VALDÍS INGIBJÖRG JÓNSDÓTTIR

The Voice
An Occupational Tool

A Study of Theacher´s Classroom Speech and the Effects of Amplification

ACADEMIC DISSERTATION
To be presented, with the permission of the Faculty of Humanities of the University of Tampere, for public discussion in the Auditorium A1 of the Main Building, Kalevantie 4, Tampere, on November 7th, 2003, at 12 o’clock.

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I dedicate this thesis to all those who work to increase our knowledge of the voice and how to look after it.
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ERRATA

(1) Numbering of the following sections is erroneous:
2.3.2. should be 2.3.1.1.
2.3.3. should be 2.3.2
2.3.3.1 - 2.3.3.6 should be 2.3.2.1 - 2.3.2.6
2.3.4 should be 2.3.3
2.3.4.1 should be 2.3.3.1
5.2.4.2 - 5.2.4.3 should be 5.2.3.2 and 5.2.3.3

(2) 5.2.4 and 5.2.4.1 repeat the previous sections and should, thus, be omitted.

(3) Some names have been misspelled and should be as below
page 7, Article I: (Irma) Ilomäki
   Article V: Ilona (Siikki)
page 32, section 2.2.9.1, 2nd paragraph, first line from top: Jiang
page 90, reference 148: Haataja
page 93, ref 186: Scherer
page 95, ref 206: Sihvo

(4) Some words have been erroneously left out
page 18 lines 6 - 7 from top: ‘factors’
page 23, last sentence from bottom: ‘resonance’

(5) Some words and numbers should be replaced
page 52, 2nd paragraph, 2nd line from top: instead of ‘these’ should be ‘certain’
page 63, section 5.2.3.1, 3rd line from bottom: ‘Intra-observer’ should be ‘Inter-observer’
page 64, section 5.2.4.2 (which should be 5.2.3.2), 3rd line from top, ‘p = 0.100’ should be ‘p = 0.08’

(6) One paragraph is incorrectly placed:
page 20, section 2.2.3, first paragraph: last sentence should be the last sentence in the previous section.

(7) Printing errors and alike, should be corrected as follows
page 44, 3rd paragraph from top, 2nd line from top: improvement of
page 49, fig. 3, title: symptoms
page 54, section 4.2.3.3, 2nd last line from top: Analogous
page 63, fig 8, title: students
page 75, section 6.3.4 (should be 6.3.3), title: the
### ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AC flow</td>
<td>Alternating current or the pulsating airflow</td>
</tr>
<tr>
<td>AQ</td>
<td>Amplitude quotient</td>
</tr>
<tr>
<td>CQ</td>
<td>Closed quotient (closed time divided by the length of the fundamental period)</td>
</tr>
<tr>
<td>CIQ</td>
<td>Closing quotient (time interval from maximum flow to the start of the glottal closure divided by length of the fundamental period)</td>
</tr>
<tr>
<td>dpeak</td>
<td>Negative peak amplitude of the differentiated glottal flow</td>
</tr>
<tr>
<td>dB</td>
<td>Decibel</td>
</tr>
<tr>
<td>fAC</td>
<td>Glottal AC-flow</td>
</tr>
<tr>
<td>F0</td>
<td>Fundamental frequency</td>
</tr>
<tr>
<td>F0 time</td>
<td>Phonation time</td>
</tr>
<tr>
<td>Hz</td>
<td>Herz</td>
</tr>
<tr>
<td>ISA</td>
<td>Intelligent Speech Analyser (Speech analysis system, developed by Raimo Toivonen, M.Sc.Eng.)</td>
</tr>
<tr>
<td>LTAS</td>
<td>Long-term-average-spectrum</td>
</tr>
<tr>
<td>p</td>
<td>(Air)pressure</td>
</tr>
<tr>
<td>OQ</td>
<td>Open quotient (the ratio between the duration of the open phase of the glottal cycle and the length of the fundamental period)</td>
</tr>
<tr>
<td>RASTI</td>
<td>Rapid Speech Transmission Index</td>
</tr>
<tr>
<td>RT</td>
<td>Reverberation time</td>
</tr>
<tr>
<td>S/N</td>
<td>Signal-to-Noise ratio</td>
</tr>
<tr>
<td>SPL</td>
<td>Sound pressure level</td>
</tr>
<tr>
<td>SQ</td>
<td>Speed quotient (the ratio between the duration of the glottal opening and the closing phase)</td>
</tr>
<tr>
<td>T</td>
<td>Length of the fundamental period</td>
</tr>
<tr>
<td>VAS</td>
<td>Visual Analogous Scale</td>
</tr>
<tr>
<td>WIPI</td>
<td>Word Intelligibility by Picture Identification</td>
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LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original studies which are referred to in the text by their Roman numerals.


SUMMARY

Teachers are professional voice users who experience a high risk of developing voice problems and, indeed, voice problems are common among teachers world-wide. Their unfavourable working conditions are identified as the principal reason for voice problems: they are often required to teach in large classrooms with poor acoustics, background noise and at too great a distance from some of their pupils. These same circumstances create in their turn unfavourable listening conditions for pupils: the teacher's voice cannot be heard sufficiently well throughout the classroom and because of the unsatisfactory signal-to-noise ratio the speech content cannot be clearly perceived against the level of background noise. For the teacher, such teaching conditions tend to result in strenuous phonation with raised sound pressure level (SPL) and fundamental frequency (F0) and more hyperfunctional voice production with stronger collision forces between the vocal folds. This means that more loading is imposed on the vocal folds during vibration. If vocal loading is sustained over long periods it can lead to vocal fatigue (which evidences itself in poorer voice quality, e.g., cloudiness and roughness), or even to pathological changes in the vocal fold tissue.

This study addressed one possible solution which may serve to improve teachers’ vocal ergonomics and pupils’ and students’ listening conditions - the use of electric sound amplification in the classroom.

AIMS

This study was designed to a) investigate the effects of amplification on the vocal parameters of teachers' voices in classroom and b) collect data on students’ and teachers’ opinions on amplification.

Six questions were addressed:

1. Does amplified or damped (i.e. reading with ear plugs) auditory feedback lower the average F0 and SPL in text reading? (Study I)

2. Does the use of amplification lower F0 and SPL of the teacher's classroom speech? (Study II)

3. (a) Is there a change in vocal parameter values or in perceptual voice quality during a teacher's working day? (b) Is this change different when amplification is used in classrooms? (Studies IV and V)

4. Does the use of amplification in classrooms diminish the teachers' symptoms of vocal fatigue? (Study III)

5. Does the use of amplification in classrooms make it easier for pupils to listen to the teaching? (Study III)
6. What other advantages and disadvantages of the use of amplification in classroom will be reported by the teachers and students? (Study III)

SUBJECTS AND METHODS

STUDY I (a laboratory study). Six females without any known voice or hearing problems read aloud a text that consisted of 133 words containing no /s/ phoneme. The subjects read the text aloud twice under normal conditions and then twice while hearing their own voices amplified through headphones (the level of amplification was held constant).

A damping test was carried out two to six months after the amplification test. The scheme was the same as in the amplification test except the subjects now read the text aloud wearing foam plastic earplugs.

The reading samples for both amplification test and damping test were recorded six times on three days (once every morning or midday and once in the afternoon or evening). Recordings were analysed for F0 and SPL (both total SPL and SPL at given frequency ranges) with a signal analysis system called Intelligent Speech Analyser (ISA), developed by Raimo Toivonen, M.Sc.Eng.

STUDY III. Thirty-three teachers (26 females and 7 males with teaching experience ranging between 1 and 32 years) participated voluntarily with their students from three Icelandic educational levels - the basic school system (for children 6 – 15 years in age), a junior college (for students 16 – 20 years in age) and a university. In total, 791 students (446 females and 345 males) participated. The teachers used amplification in class for at least a week. The wireless equipment consisted of a Lavalier (chest borne microphone) with transmitter and receiver. A portable loudspeaker was used by all but two of the subjects, who used loudspeakers fastened to the wall. The transmitter was battery-powered, while the rest of the equipment was powered through the mains.

At the end of the research period the teachers answered two questionnaires. One, with 19 multiple-choice questions, was designed to elicit background information. The other one, with 13 multiple-choice questions, was designed to obtain their opinions on the advantages and disadvantages of using amplification in class. Students aged 10 years and older (n=664) received a multiple-choice questionnaire about the advantages and disadvantages they experienced when their teachers were using amplification in class. In all these questionnaires the respondents were required to choose from the alternatives ‘considerable - some - little - nothing’.

Students aged 6 - 9 years (n=127) were asked two questions: (1) Did you like it when your teacher used an amplification system? (2) Why?

STUDIES II, IV,V (field studies). Five teachers (three females and two males; mean age 51 years), all with long teaching experience, volunteered themselves from the group of 33 teachers who took part in Study III. All suffered from multiple vocal symptoms (3 or
more symptoms) that occurred principally during the term. A clinical examination of each subject was performed before the experiment started. No pathological changes were found. Background information was gathered with a questionnaire. The subjects’ classroom speech was recorded on a portable battery-operated DAT recorder. The recordings took place in the first and last lessons of the working day which the subjects had chosen as being the most difficult on their timetables; the samples were taken first without amplification and then a week later with amplification (the teachers having used the amplification system for the whole of that week). Samples lasting from two to four minutes were taken for analysis from the very beginning, from the middle, and from the end of each lesson.

For Study II, the variables analysed were average F0, SPL and phonation time.

For Study IV, F0 and SPL were analysed. F0 and SPL were measured with an analogous system (F-J electronics) and analysed with a micro-computer.

For Study V, spectral changes were studied with ISA and the voice quality was evaluated by two professional voice trainers.

In all studies a comparison was made between the vocal characteristics of unamplified and amplified speech.

RESULTS

STUDY I. Both amplified and damped auditory feedback led to a significant decrease in F0 and SPL values (Student’s t-test). Additionally, amplified feedback was associated with 1) lower alpha ratio and 2) a decreased level difference between the ranges of F1 and F0 when compared with unamplified feedback.

STUDY II. Amplified auditory feedback in the classrooms led to a statistically significant decrease in the average F0 and SPL (Student’s t-test). Amplification did not significantly affect phonation time.

STUDY III. The majority of teachers and students found amplification beneficial and the few disadvantages mentioned were mainly technical problems, frequently due to a lack of knowledge of how to use the equipment. With amplification teachers found it easier to talk and experienced less fatigue in the vocal apparatus. Students found it easier to hear the teacher through class chatter and easier to follow the lesson.

STUDY IV. F0 and SPL increased on average during the teachers’ working day both with and without amplification. The increase was larger and for F0 statistically significant when amplification was used. Correlation was found between F0 and SPL both in ordinary and amplified conditions. Relatively large changes were found in F0 during the lesson.

STUDY V. The slope of LTAS was steeper and SPL lower when amplification was used. When amplification was used the slope decreased significantly and SPL rose during the working day. The two male subjects showed somewhat different results from the females. The spectral tilt in the male voices decreased less compared to the female voices or even
increased at some ranges during the day when amplification was used. In perceptual evaluation the overall voice quality was identified as better when amplification was used.

CONCLUSIONS

Both teachers and pupils agreed that amplification in classroom was beneficial, and the results suggested that amplification in class may be ergonomically desirable both for teachers’ voices and for students’ listening effectiveness.

Amplified auditory feedback significantly lowered F0 and SPL and the spectral slope became steeper, both in laboratory and in classrooms, which indicates less strenuous voice use. When compared with unamplified lessons, the fundamental was relatively stronger and the overtones were weaker, indicating softer collision of the vocal folds and, consequently, less stress imposed on the vocal folds. The results from damped auditory feedback showed also a significant decrease in F0 and SPL and in this case F0 decreased relatively more than SPL when compared to the effects of amplified auditory feedback. It should be noted that dampening effects from earplugs may cause the voice to sound darker. Voices with darker timbre tend to be heard as lower in pitch and this may therefore have caused a larger decrease in pitch.

Average F0 and SPL increased and the spectrum slope became less steep during the teachers’ working day both with and without amplification; the increase was greater when amplification was used. It has been hypothesized that a sufficient vocal loading-related rise in F0, SPL and decrease in spectrum slope show the vocal organ’s ability to adapt adequately to vocal loading. The use of amplification may therefore indicate that the vocal organs are undergoing adaptation to vocal loading. It can result from increased activity in the respiratory and laryngeal muscles or it may reflect decreased tissue viscosity. In contrast, a negligible rise or fall in these vocal parameters could be a sign of vocal fatigue. No significant change was seen in phonation time. As the subjects felt less vocal fatigue when using amplification the increase in F0 and SPL and decreased spectral tilt may be interpreted not as a sign of vocal fatigue but rather a reflection of a normal adaptation to loading. It could also suggest that the subjects were more tolerant of an increase in these parameters during the day as the F0 and SPL were lower when using amplification.

In unamplified lessons no significant changes in spectrum were observed and more vocal fatigue was experienced. Therefore, a hypothetical interpretation is that there was inadequately high muscle tension in the vocal apparatus right from the beginning of the working day. The results were more prominent in females, suggesting that there may be possible gender-dependent differences in loading-related changes in vocal parameters that warrant further investigation.

The voice quality was perceived better in the amplified situation, pointing to a less strained voice use. However, the apparent strain increased during the working day, which is in accordance with the larger decrease in spectral tilt. In general, perception of various
vocal characteristics correlated in a rational way with changes in the spectrum. Overall voice quality correlated positively with increased spectral tilt, which is in contrast to earlier findings showing that a good speaking voice quality was characterized by a less steep spectral slope. The reason could be that the voice samples in this study were not taken from voice use at habitual conversational volume but from speech in the classroom, where teachers were required to project their voices. All voices in the present study were perceived as more or less strained and the quality was regarded as good in none of the samples. The reason may be that all these teachers had long teaching experience in an environment known to be harmful to the voice.
1. INTRODUCTION

1.1. THE VOICE AS AN IMPORTANT BUT VULNERABLE FACTOR IN TEACHING EFFECTIVENESS

To ensure effective communication, it is important that:

a) teachers are able to communicate with their students without endangering their voices and b) the students are able to hear what the teachers are saying without too much difficulty. These two factors must certainly go hand-in-hand if teaching is to show good results. Unfortunately, the classroom environment, where there is often too much noise and where long distances are frequently imposed between teachers and learners, places the teacher's voice at risk of damage and makes it difficult for many of the students to hear the teacher properly.

In spite of modern innovations in teaching methodology, the voice remains the most important working tool of the teacher: “It is a sine qua non that an audible and durable voice is a prerequisite of oral teaching” (Ohlson, 1988, p112). According to Borden and Harris, 1984 (p159): “The goal of the speaker is to produce sounds that fit an auditory perceptual target in order to be understood by the perceptual system of a listener”. Factors which can prevent the teachers’ orally delivered information and instruction from reaching the ears of the learners may be of physiological, psychological or environmental origin, or a combination of all these factors, and may originate either with the teacher or the learner, or both.

Teachers are one of the largest groups of professional voice users: e.g., in the USA they are the second largest group after salespersons (Titze et al., 1997), in Finland the third largest group after foremen and salespersons (Laukkanen, 1995) and in Sweden the third largest group after salespersons and health care professions (Fritzell, 1996). Of all occupations, those engaged in teaching are considered to be the most at-risk of incurring voice problems (Verdolini and Ramig, 2001; Vilkman, 2001). Twenty to eighty percent of teachers have, according to several research questionnaires, reported that they suffer from various vocal symptoms, the most common of those being dryness in the throat and vocal fatigue, considered to be due to prolonged voice use while teaching (e.g., Russel and al., 1998; Sapir et al., 1993; Gotaas and Starr, 1993; Pekkarinen et al., 1992; Ceuppens, 1995; Smith et al., 1997). Indeed, Swedish research results suggest that the teachers are the largest group of professionals seeking medical help for vocal symptoms (Fritzell, 1996). Unger and Bastien (1981) and Herrington et al. (1988) also found teachers prominent amongst those seeking medical help for voice problems.

According to questionnaire responses from 189 teachers and 91 controls (Morton and Watson, 1998) temporary illness associated with voice problems is considerably more common amongst the teachers than amongst the controls. Additionally, research findings have suggested that between one fifth and one third of teachers are absent from work as a
result of voice problems during a working year (Smith et al., 1997; Sapir et al., 1993). It is calculated that in the USA these societal losses due to voice disorders in teachers cost about $2.5 billion annually (Verdolini and Ramig, 2001). It is therefore clear that we are talking about an occupational health issue which affects both the individual and the society in general.

In the questionnaire research by Smith et al. (1997), half of the teachers indicated that they were currently hoarse in comparison to one fifth of the control subjects. In a questionnaire study, the most frequently cited symptoms in 274 male and 280 female teachers were hoarseness, a fatigued voice and discomfort when speaking loudly (Smith et al., 1998 (a)). In classroom conditions a hoarse and low-pitched voice or a soft, asthenic voice makes it difficult for the students to hear the teacher.

It is rather common to attribute vocal symptoms such as hoarseness to teachers' misuse of their voices. However, this can be misleading as it gives the impression that teachers have some choice in the matter. It would be more accurate to say that teachers are forced into strenuous prolonged voice use because of unfavourable environmental, physiological and psychological factors, each of which can be harmful to the voice. If we look at the problem from this angle, we are talking about occupational hazards, factors inherent in the working environment and the nature of the profession. “As to the risk factors, the main hazard can be considered to be prolonged use of the voice itself” (Vilkman, 2001). The condition of the voice of these professional voice users is serious and detracts from the individual's ability to work in a normal way. In consequence, the Voice Commission of the Union of European Phoniaticians (UEP) and Pan-European Voice Conferences (PEVOC) recently set up a study programme concentrating on voice as an occupational safety and health (OS&H) issue. The results strongly indicated that the OS&H situation of voice and speech professionals is poor in Europe (Vilkman, 2001). It is clear that the voice has still not received recognition as an occupational tool to which employers must give care and attention. “For some reason these professions are not understood in the same basic terms as other professions” Vilkman (2001). Sala et al. (2002) indicate certain difficulties in having voice disorders specified as an occupational disease; they do not fall directly within the usually accepted definition of what constitutes an occupational disease i.e. a disease the primary cause of which is exposure at work to causal factors of either a physical or a chemical nature.

As far as teachers are concerned, study results have shown that voice problems are common among teachers world-wide (Russel et al., 1998; Sapir et al., 1993; Gotaas and Starr, 1993; Morton and Watson, 2001; Comins, 1992 and 1995; Pekkarinen et al., 1992; Smith et al., 1997; Ceuppens, 1995; Vilkman, 1996; Vilkman, 2000; Verdolini and Ramig, 2001, Titze et al., 1997). In the case of students, results have shown that the educational environment leaves a great deal to be desired. Research results have indicated that the signal to noise ratio (in this instance the teacher's voice measured against the background noise in the classroom) does not reach recommended levels for young or handicapped listeners (15 dB) (Sanders, 1965; Crandell and Smaldino, 1995 (a and b); Finitzo - Hieber, 1988; Leventhall, 1998) and the distance from the teacher may be too great to allow the students to hear clearly the teachers’ instructions (Leavitt and Flexer,
1991; Crandell and Smaldino, 1994; Crandell and Bess, 1986). For the sake of teachers' voices and for pupils' ability to hear, there is a need for considerable ergonomic improvement in the average working classroom. Consequently, in this preliminary study teaching effectiveness has been investigated from the point of view of the teacher’s voice and the learners’ ability to hear.
2. REVIEW OF THE LITERATURE

2.1. EFFECTIVE COMMUNICATION IN CLASS

Whatever may be the impact of modern technology on teaching methods in the future, it is a fact that up till now teachers have relied on the unaided use of the human voice to transmit information and instructions from teacher to learner. An audible and durable voice, a satisfactory acoustic environment and an appropriate distance between the listener and the speaker are fundamental to all successful lessons.

2.1.1. Teachers’ effectiveness: the role of the voice

Schmidt et al. (1998) have examined teachers’ overall effectiveness using perceptual and acoustic measurements from voice samples. Acoustic analyses were carried out from 200 voice samples for each of 7 teachers performing a 10-12 minute lecture. A perceptual evaluation was provided by 180 undergraduate and graduate students. The results indicated that the greater the frequency range and the frequency variability, and the lower the rate and number of dysfluencies, the more effective was the teacher considered to be.

Some research results have indicated that students form unfavourable views of the speakers when they find their voices unpleasant to listen to (Blood et al., 1979; Wanser and McCroskey, 1998; Lallh and Rochet, 2000) In those study designs the listeners listened to the voice samples without being able to see the speaker. It would have been interesting to see whether the conclusions would have been different if they had done so. Wanser and McCroskey (1998) studied the effects of the teachers' socio-communicative style on the students' opinions on the teacher and the learning material. They concluded that first and foremost “students desire lecture material which they can understand and hear”. According to this it would appear that the attractiveness of a teacher's voice is not a major factor when considering teaching effectiveness. However, up till now surprisingly little attention has been paid to the importance of teachers' voice quality and voice capacity in communicational and audiological research on effective teachers’ behaviour in class.

It is undeniable that voice problems can impair a teacher's working efficiency. In a questionnaire-based research into the impact of voice problems on the quality of life, half of the 174 patients seeking treatment for voice problems stated that their problems had negatively affected their past (53%), current (49%) and future (76%) working abilities (Smith et al., 1996). Indeed, the more acute the voice problems are, the more seriously they detract from the patients' quality of life (Jacobson et al., 1997).
2.1.2. Students’ ability to hear

Effective listening requires the ability to hear (i.e. normal hearing or adequate artificial compensation for it), good acoustics in the classroom, an appropriate distance between teacher and learners, an audible speech signal, and familiar and easily understood language where the main factors considered to determine whether speech is intelligible are a) spectral components, b) the timing of acoustic events and c) the position of the voice source in relation to the listener (ASHA, 1995; Finitzo-Hieber, 1988; Crandell and Bess, 1986; Pekkarinen, 1988; McGlashan and Howard, 2001; Wanzer and McCroskey, 1998; Howard and Angus, 2001).
2.2. THE VOICE

2.2.1. Acoustic and perceptual characteristics of the voice

In voice research, voice is studied in terms of physiological factors (e.g., activity in respiratory, laryngeal or articulatory muscles), physical factors (e.g., expiratory force), acoustical factors (study of sound) and perceptual factors (how voice is perceived). According to Hirano (1975) voice is studied from parameters a) which regulate the vibratory pattern of the vocal folds (in terms of physiological and physical activity), b) which specify the vibratory pattern of the vocal folds (in terms of physical) and c) which specify the nature of the sound generated (in terms of acoustical and perceptual). Parameters which specify the nature of the sound generated can be summarized as in table 1. Some of these factors will be discussed in more detail in what follows.

Table 1. Factors which specify sound generated. Modified from Hirano, 1975. The factors on the left and the right describe the same phenomenon from different points of view (acoustical and perceptual)

<table>
<thead>
<tr>
<th>Acoustic</th>
<th>Psycho-acoustic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude (Intensity)</td>
<td>Loudness</td>
</tr>
<tr>
<td>Fundamental frequency</td>
<td>Pitch</td>
</tr>
<tr>
<td>Waveform. The acoustic spectrum</td>
<td>Quality</td>
</tr>
<tr>
<td>Fluctuations : 1) large, slow changes</td>
<td>Fluctuations: 1) Trembling</td>
</tr>
<tr>
<td>2) small, rapid, irregular</td>
<td>2) Hoarseness</td>
</tr>
</tbody>
</table>

2.2.2. Glottal vibrations

“The aerodynamic aspect of phonation is characterized by four factors: subglottal pressure, supraglottal pressure, glottal impedance and the volume velocity of the airflow at the glottis” (Hirano, 1981, p25). Before vocalisation can begin the vocal folds are adducted using adductor muscles and as Borden and Harris (1984, p82) state: “A necessary condition for voicing is that the air pressure below the folds must exceed the pressure above the folds”. During the course of vocalisation the vocal folds are brought together by the so-called “Bernoulli force”, causing the vocal folds to vibrate owing to differences in the air pressure above (supraglottal) and below (subglottal) them. Each sine wave in those vibrations has its own characteristics, as described by Leavitt (1978): “Three basic components of a simple periodic vibration are frequency, intensity and phase”.
2.2.3. **Intensity regulation**

“The average or overall sound pressure level in decibels provides an indication of the strength of the vocal fold vibration. If a person speaks softly, the overall sound pressure level (SPL) will be low. Conversely if a person speaks loudly, the overall SPL will be high” (Colton and Casper, 1990, p22).

The intensity of the voice is measured acoustically as sound pressure level (SPL) by the formula:

\[
\text{dB (SPL)} = 20 \log_{10} \left( \frac{P_0}{P_r} \right)
\]

where \( P \) is the sound pressure of voice (in Pascals, Pa). \( P_0 \) refers to the pressure measured (the output), \( P_r \) refers to the pressure used for comparison or the standard reference pressure 20\( \mu \)Pa (the lowest sound pressure detectable by the humans). Intensity is proportional to the pressure squared (Leavitt, 1978, p60).

2.2.3.1. **Subglottic pressure**

In the literature it is demonstrated that the loudness of phonation is mainly controlled by subglottic pressure (the expiratory effort that determines the flow rate) (e.g., Sundberg, 1987; Gauffin and Sundberg, 1989; Borden and Harris, 1984). In normal speech the subglottic pressure ranges from 5 -10 cm H\(_2\)O. See Hirano (1981, p38) for further review.

A doubling of the subglottic pressure leads to 9 dB increase in the sound pressure level (Sundberg, 1987, p39). The louder the voice the more subglottic pressure is exerted, and the subglottic pressure tends to be highest for high pitched sounds (e.g., Isshiki, 1964). There is a six to sevenfold increase in subglottic pressure if the voice is raised from soft to loud phonation (for females from 0.33 to 2.02 kPa; for males from 0.33 to 2.29 kPa; 1 kPa = 10 cm of H\(_2\)O), resulting in higher SPL and higher F0 (Vilkman et al., 2002). The average variation range of subglottic pressure seems to remain stable throughout adulthood and does not differ by gender (Hiss et al., 2001). Subglottic pressure which is affected by resistance against the flow of air through the glottis is significant for the amplitude and also to some degree for the frequency of phonation. When subglottic pressure is raised an increased adduction may be required for continuing the vocal fold vibration. When we increase loudness of phonation we have a tendency to increase both vocal fold tension and adduction. An increase in phonation frequency does not necessarily cause an increase in subglottic pressure. Under such circumstances a manipulation in laryngeal muscles takes place (Sundberg, 1987, p16).

2.2.3.2. **The negative peak amplitude of differentiated glottal flow**

The amplitude characteristics of glottal flow can be determined by AC amplitude of glottic flow (\( f_{AC} \)) and negative peak amplitude of differential glottal flow (\( d_{peak} \)) (also called “maximum flow declination rate” by Holmberg et al., 1988). Holmberg and colleagues (1988) found, when shifting from normal to loud voice use, increased
subglottic pressure, increased AC flow and an increased maximum airflow declination rate. An increase in $d_{\text{peak}}$ values is associated with increased energy of the harmonics and intensity of voice (Gauffin and Sundberg 1989, Alku et al., 1999)

2.2.3.3. Resonance

As the subglottal pressure seems to be the main factor in controlling the intensity, the vocal tract as a resonator appears to play a definite role in providing for an increase in the SPL. The first 4 formants (formant = a resonance of the vocal tract) are considered the most relevant ones (Sundberg, 1987, p12). This is because these lowest formants naturally fall to the lowest and thus strongest overtones of the voice and consequently the acoustic energy of these lowest formants is greatest. The whole voice gets stronger. Additionally, the voice can become stronger if two or more resonances approach each other. If the frequency distance between two adjacent resonances is halved, both resonances gain 6 dB and the overtones between these resonances gain 12 dB (Sundberg, 1987, p95). When singing at high pitch sopranos learn to raise F1 (by opening the mouth wider) to the frequency of F0 and may gain even 30 dB in intensity (Sundberg, 1987, p126-127). Lip radiation also increases SPL for 6 more dB per octave (Howard and Angus, 2001, p31)

2.2.3.4. Role of F0

Raising F0 actively (e.g., by contraction of the crico-thyroid muscle) is an effective way of raising intensity. Seidner (1986) pointed out that speaking pitch may rise one octave from normal speech to shouting. With increased F0 there is less time for the vocal folds to make their movement and therefore the closing phase is faster, resulting in increased intensity as $d_{\text{peak}}$ increases. Additionally, subglottic pressure raises F0 since it stretches the vocal folds laterally and thus makes them stiffer (Titze, 1984). Stiffer material, in turn, vibrates at a higher frequency.

2.2.4. Intensity and loudness

The term “loudness” is used for the psychological sensation of a sound i.e. how the human ear judges the intensity. Intensity and loudness are not perfectly correlated as the sensation of loudness increases more slowly than the actual increase in intensity (Borden and Harris, 1984, p40). Voice quality can affect loudness even without affecting intensity. According to Sundberg (1987) a rise of subglottal pressure from 7–14 cm H2O raises the fundamental frequency about 28 Hz in moderately loud voices.

For example in a study by Lauri et al. (1997) the difference between soft and loud speech phonation was measured and results showed a rise from 62.9 dB to 98.7 dB for female voices. In a study by Vilkman et al. (2002), the rise was from 63.8 dB to 100 dB for male voices. According to this the difference between soft and loud speech phonation is approximately the same for both genders, roughly 30 dB. However, the variation between soft and loud voices can exceed 60 dB in singing (Åkerlund and Gramming, 1994; Titze, 1994). Coleman et al. (1977), using phonetogram procedure, measured the highest
intensity for a female voice at 122 dB and for a male voice at 126 dB. The minimum SPL was measured at 48 dB for a female and at 51 dB for a male. The distance from the microphone to the speaker’s lips was six inches.

Vocal intensity has been assigned to 3 levels by Buekers et al. (1995) where the microphone distance was 30 cm from the mouth and Vilkman et al. (2002), where the microphone distance was 40 cm from the mouth:
- Soft speech < 50 – 70 dB
- Loud speech 70 – 90 dB
- Screaming 90 dB.

Table 2 shows the vocal effort of a speaker measured at two different distances according to international standard assessment. Webster (1979) pointed out that speech sounds vary widely in SPL and F0 during speaking. Under most conditions (up to 78 dB(A)) when a person is instructed to speak in a “normal” tone of a voice the A-weighted sound level for most talkers is usually 50-65 dB(A) at a distance of 1 m from the talker. As the ear is not equally sensitive to all frequencies, a frequency-weighting method, called A-weighting, is used to imitate human hearing. Lower frequencies (below 1000 Hz) are damped with respect to the middle (between 1 and 5 kHz) and high frequencies (over 5 kHz) “A-weighting has a frequency dependence that corresponds to that of the equal-loudness contours at low levels” (Zwicker and Fastl, 1999, p205).

Table 2. The vocal effort of the speaker according to ISO 9921-1, 1996

<table>
<thead>
<tr>
<th>Vocal effort</th>
<th>A-weighted sound level dB(A) at 1 meter</th>
<th>A-weighted sound level dB(A) at 0.3 meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>Shout</td>
<td>84</td>
<td>94</td>
</tr>
<tr>
<td>Very loud</td>
<td>78</td>
<td>88</td>
</tr>
<tr>
<td>Loud</td>
<td>72</td>
<td>82</td>
</tr>
<tr>
<td>Raised</td>
<td>66</td>
<td>76</td>
</tr>
<tr>
<td>Normal</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>Relaxed</td>
<td>54</td>
<td>64</td>
</tr>
</tbody>
</table>

Circumstantial factors such as background noise, acoustics and distance can affect the intensity of the voice. For example, a speaker has a tendency to increase SPL when speaking against a background noise (Lombard’s effect; van Heusden E, Plomp R, Pols LCV: Effect of ambient noise on the vocal output and the preferred listening level of conversational speech. Appl Acoust 1979;12:31-43.). Room acoustics affect the dB level that is obtained e.g., to phonate at 80 dB measured at a distance of 1 meter is much easier in an office with an average reverberation time than in a well damped studio. There is also a tendency for a speaker to raise the SPL in large rooms or when speaking to a large audience. Therefore in work places where speech communication is essential it is recommended that the A-weighted sound level for background noise does not exceed 63 dB(A) for satisfactory communication at the distance of 2 meters (Webster, 1979).
2.2.5. Fundamental frequency and pitch

F0 is assumed to be controlled mainly by a) contraction in cricothyroid muscles (CT), b) contraction in thyroarytenoid (TA) muscles and c) by changes in lung pressure (Titze, 1994). Thus, phonation frequency is mainly determined by the length, mass and tension of the vocal folds and changes in subglottal pressure. Furthermore, Vilkman and Karma (1989) showed that vertical position of the hyoid bone causes vertical stretch to the laryngeal tissues and raises F0. Additionally, different vowels seem to cause small but significant differences in F0 values in speech utterances i.e. high vowels tend to have a higher F0 and low vowels have a lower F0 (Honda and Fujimura, 1991). This is assumed to be partly caused by the tongue’s effect on laryngeal position and reflexive CT activation in vowel articulation (Honda, 1983).

According to the literature (See for a further review Krook, 1988) the mean F0 for female voices at conversational loudness can vary between 164 and 255 Hz and for male voices between 100 and 146 Hz. The individual “habitual pitch” (the voice used in neutral speech during the day without any vocal loading) varies relatively little, as measured from day to day, and even from year to year (Coleman, 1993). If the voice loudness is raised from soft phonation to loud phonation the F0 variation can be doubled or more. For example in a study by Vilkman et al. (2002) the mean rise was 149 Hz for female voices (from 153 Hz to 302 Hz or about 12 semitones) and 150.9 Hz for male voices (from 91.1 Hz to 242 Hz, or about 19 semitones) when shifting from soft to loud voices.

A number of researchers have shown that there may be considerable differences between individuals, both male and female, in the mean F0 of their voices, and there can also be differences in F0 between samples of speech spoken by the same individual. These differences in mean F0 have been attributed to various causes (e.g., cultural and linguistic factors.) For example, the mean F0 in Swedish female voices has been reported to be lower than the mean F0 in English, French and German voices (Krook, 1988). Emotional factors also affect F0 in speech. For example, emotions such as anger and enthusiasm are typically related to higher F0 (and SPL; see, e.g., Laukkanen et al., 1996). Circadian rhythms (i.e. the changes in body temperature and heartbeat during 24 hours) significantly affect F0. According to Bouhuys et al. (1990) in 14 depressed patients F0 was shown to follow the circadian pattern: mean F0 measured as semitones tended to rise from 1 am to 10 am by 0.6 semitones, stay steady between 10 am to 1 pm, and then decrease by about 0.2 semitones till about 7 pm, to rise again by 0.1 semitones till 10 pm. Other factors may include variations in the ages of the subjects (Luchsinger and Arnold, 1965; Honjo and Isshiki, 1980) different sizes of the larynx (Titze, 1994) and state of health. Differences in the range of testing materials used may also affect measurements e.g., whether the subjects were required to read a text, or to speak spontaneously, or to sustain a single vowel. See for further review Rantala et al. (1997).

Like intensity and loudness, fundamental frequency and perceived pitch are not exactly equivalent. Physiologically, the fundamental frequency (F0) is the number of vocal fold vibrations per second (f); acoustically, it is the inverse of period (T) length or $f = 1/ T$.
(Leavitt 1978, p49). Perception of pitch, on the other hand, is subjective. Voice quality, signal duration and also to some extent sound intensity affect our judgement of pitch (Zwicker and Fastl, 1999). Timbre affects pitch perception so that sound with a brighter timbre sounds higher in pitch. In terms of acoustic measurement F0 is measured as Hz, but for perceptual judgement variations in F0 are measured as semitones by the formula $39.86 \times \log \left( \frac{F0}{16.35} \right)$ (Frokjær Jensen and Prytz, 1976).

Environmental circumstances can affect the pitch; it is automatically raised against noise, in larger rooms and/or to larger audience (Van Heusden, 1979). The degree of indulgence in damaging activities may also be significant. The pitch becomes lower when the subjects are heavy smokers (Stoicheff, 1976; Comins, 1990; Murphy and Philip, 1987).

In their investigations on the speaking fundamental frequency of storytellers, made over a number of years, Coleman and Markham (1991) assumed that a variation which amounts to $\pm 3$ semitones in repeated measures of average speaking fundamental frequency may be considered a realistic value for variation of F0 range in speech.

### 2.2.6. Phonation time (F0 time)

Phonation time is the time during which the vocal folds are vibrating. It is possible to estimate the total number of vocal fold vibrations and thereby the work loading on the vocal folds. By excluding all pauses and voiceless segments of speech the number of cycles per second is multiplied by the vibration time of the vocal folds and the result is divided by one thousand (called “index of voice loading” by Rantala and Vilkman, 1999):

\[
\frac{(F0 \times \text{F0 time})}{1000}
\]

F0 time is given in seconds. Rantala and Vilkman (1999) found that the index correlated positively with the number of the subjects’ voice complaints i.e. the more voice complaints the subjects had, the higher was the value of the index of voice loading.

### 2.2.7. Voice quality

#### 2.2.7.1. Laryngeal level

“Personal voice characteristics are determined by the formant frequencies and the voice source” (Gauffin and Sundberg, 1989). The sound that comes from vocal fold vibrations is called “voice source” and is mainly controlled by means of the respiratory and laryngeal muscles. Voice source is characterized acoustically by fundamental frequency, amplitude and spectrum, or perceptually by pitch, loudness and timbral characteristics (Sundberg, 1987, p51). The opening and closing of the glottis result in a sequence of quasi-periodic air pulses sent into the vocal tract which may be regarded as a resonator. As the shape of it is easily changed by movements of the articulators it affects the
frequencies of a voiced sound during speech. Those resonance frequencies created in the vocal tract are referred to as “formants” (Titze, 1994, p143). To estimate the original glottal flow waveform or the voice source inverse filtering is used. By inverse filtering, the formants can be cancelled making it possible to study the vocal fold vibrations (Titse, 1994, p333; Sundberg, 1987, p77).

Measurement of the voice source may include measurement of AC amplitude and several time-based parameters (fig. 1).

![Figure 1: Two periods of a glottal flow (top panel). f_{AC} = amplitude of the flow. Open quotient (OQ = t1 + t2 / T). Speed quotient (SQ = t1 / t2). Closing quotient (CQ = t2 / T) where T denotes the length of the fundamental period (T = t1+t2+t3). The bottom panel shows the first derivative of the glottal flow. d_{peak} = negative peak amplitude of the differentiated glottal flow. Figure from Alku et al. (1998).](image)

There are different modes of phonation. In breathy or hypofunctional voice production the adduction is not sufficient in relation to subglottic pressure. Therefore the glottis does not close completely and the voice source amplitude is relatively large (higher peak flow) and the relative closed time of the glottis is short. There is a longer delay between peak flow and peak differentiated flow (relatively slow closing of the glottis). SPL is typically low. In contrast, phonation becomes “pressed” (i.e. strained) or hyperfunctional as the adduction force is exaggerated i.e the adduction is too strong in relation to subglottic pressure. Then the voice source amplitude is small (low peak flow), the closed time is longer and there is shorter delay between peak flow and peak differentiated flow (relatively fast closing of the glottis) (Gauffin and Sundberg, 1989; Sundberg et al., 1993).
A description of a certain aspect of the voice source is its composition of harmonic partials, the frequencies of which are \( f_1 = 1 \times F_0 \), \( f_2 = 2 \times F_0 \), \( f_3 = 3 \times F_0 \), \( f_4 = 4 \times F_0 \) i.e. the frequencies which form a harmonic series. Harmonic partials can be studied with spectrum analysis. Borden and Harris (1984, p279) defined amplitude spectrum as “A graphic representation of a vibratory event in which the ordinate (the vertical axis) represents the amplitude of the signal while the abscissa (the horizontal axis) represents the component frequencies”.

The lowest tone in the spectrum is called “fundamental” and all other tones “overtones”. The level of the fundamental depends on the amplitude of vocal fold vibration. This, in turn, correlates with the amplitude of AC flow (the pulsating airflow) in voice source. The greater the amplitude, the stronger the fundamental frequency. The overtone content of the voice source depends on how fast the glottis cuts off the transglottal airflow in the closing phase; the faster the closure, the stronger the overtones (Gauffin and Sundberg, 1989). When loudness of phonation is increased, the amplitude of the spectral overtones increases considerably more than the amplitude of the fundamental, and higher overtones tend to increase more than lower overtones. An overtone is often the strongest partial in loud phonation rather than the fundamental (Fant, 1960). On the other hand, lower source spectrum partials are much more prominent in quiet phonation than in loud phonation.” (Sundberg, 1987, p72).”

The smoother and more sinusoidal the waveform is, the softer the higher partials are, and conversely, the more abrupt the changes are in the waveform, the stronger the high partials of the spectrum will be. This is in line with the results of Hammarberg (1992), according to which the level of the fundamental frequency is low relative to the first formant in hyperfunctional and strained voices, while the opposite is true for hypofunctional and breathy voices. Male voices have a weaker fundamental in source spectrum than female voices which are characterised by a strong source spectrum fundamental (Sundberg, 1987, p67).
Voice quality refers to perceived impression of voice, and the main acoustic correlate of it is sound energy distribution along the frequency range. Voice quality (at the laryngeal level) is partly due to the way in which the vocal folds vibrate, partly to how closely the vocal folds are aligned (e.g., influenced by the presence of irregularities along the edges of the folds (Borden and Harris, 1984, p87). “Timbral characteristics depend on the properties of the vocal fold vibrations which in turn depend on both the laryngeal musculature and the subglottal pressure” (Sundberg, 1987, p44).

Sound energy distribution is studied by measuring acoustic energy in selected frequency ranges. This can be achieved by measuring a factor called Long-term-average-spectrum (LTAS). “The long-term-average-spectrum provides information on the spectral distribution of the speech signal over a period of time” (Löfqvist and Manderson, 1987). The measure of SPL difference between the ranges 0 – 1 kHz and 1 - 10 kHz provides a measure of the overall tilt of the spectrum. According to Löfqvist (1986) a high value of (SPL 0-1 kHz) - (SPL 1-10 kHz) indicates that the fundamental and the lower harmonics dominate. The spectrum thus falls off rapidly (soft or hypofunctional voice). Conversely, a low value shows that the source spectrum has a lower spectral tilt (strong or hyperfunctional voice) (Childers and Lee 1991, Gauffin and Sundberg, 1989). Inverse results will be obtained if the level difference is calculated either as energy in 1-10 kHz / energy in 0-1 kHz or as (SPL 1-10 kHz) - (SPL 0-1 kHz) (alpha ratio, Frøkjær-Jensen and Prytz, 1973 and 1976).

2.2.7.2. Voice and speech quality at the supralaryngeal level

At supralaryngeal level vocal tract resonances and formants modify sound energy distribution and thus greatly affect voice quality. On the basis of the source filter theory (Fant, 1960) the sound source is the time-varying glottal airflow and the vocal tract is the filter. During speech production, movements of the articulators cause changes in the shape of the vocal tract. The filter (the vocal tract) of the source filter model (fig. 2) is therefore time-varying during speech production. This has the effect of changing the frequencies of the formants in their response to these alterations - the so-called formant transitions. The speed of formant transitions varies with different speech sounds. In English this time varies from 10 msec for plosives (e.g., [b/p/d/t/g/k]) to 250 msec for diphthongs. The syllable length in speech is approximately 250 msec on average (Howard and Angus, 2001). According to Sundberg (1987), the movement in any of the articulators generally affects the frequencies of all formants especially the lower formant frequencies. Indeed, articulation determines the frequencies of the formants, especially for the two lowest ones which also happen to be the most important formants for linguistic information. Each vowel sound is associated with a specific articulatory profile producing a specific area function that in turn gives a specific combination of formant frequencies. The higher the formant the more its frequency depends on non-articulatory factors such as vocal tract length. Difference in pharyngeal length is significant for the timbral classification of the voice. Every vowel can be articulated in various ways with various jaw openings, various positionings and shapes of the tongue, and various larynx positions. This is reflected in varying combinations of formants.
First formant. The lowest formant up to 1 kHz. Always rises as the jaw opening is increased (Sundberg, 1987, p 99).
Second formant. Between 1 and 2 kHz. Changes considerably as the tongue shape is shifted (Sundberg, 1987, p99).
The first and second formants are the main determinants of vowel quality (Fant, 1960, p46).
Third formant. Between 2 and 3 kHz. This formant is sensitive to the position of the tongue tip or to the size of the cavity behind the front teeth. For speech perception this formant is more important for front vowels than for back vowels (Fant, 1960, p121). The three first formants for, e.g., the vowel [i:] can be for a speaker F1 300 Hz, F2 2500 Hz and F3 3000 Hz, (Borden and Harris, 1984, p102).
Fourth formant. Between 3 and 4 kHz. The fourth formant is highly relevant for the voice timbre or “to the personal component in the sound of the voice” (Sundberg, 1987, p101). Lowering of the larynx causes marked lowering of the third and fourth formant frequencies (Sundberg, 1987). These formants in particular make a significant contribution to the phonetic quality of the front vowels. As a rule of thumb, the lower the formant frequencies the darker the timbre, and the higher the formant frequencies the brighter the timbre. A bright voice with more sound energy in the 2-5 kHz region sounds louder and projects better than a darker voice. Formant frequencies are also used to carry information of e.g., emotions. The most straightforward example of this is the fact that smiling can be heard in the voice through raised formant frequencies compared to those used in neutral speech (Laukkanen et al., 1997).

2.2.8. Factors affecting the voice

2.2.8.1. Auditory feedback mechanism

Study results have identified the role of auditory feedback in monitoring and controlling speech and voice production. Auditory feedback is a fundamental necessity when singing if the singers are to hold pitch (Sundberg, 1987, p61). People seem to have a tendency to increase pitch and loudness when feedback is damped (Lane and Tranel, 1971; Chang – Yit et al., 1975). Auditory feedback is important in the control of phonatory quality. The monotonous, uncontrolled and often high pitched voices of the deaf illustrate this. A summary of studies on auditory feedback can be seen in table 3.
Table 3. A summary of studies on auditory feedback.

<table>
<thead>
<tr>
<th>Author</th>
<th>Subjects</th>
<th>Method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chang – Yit et al. (1975)</td>
<td>6 3</td>
<td>Auditory feedback modulated gradually during a session.</td>
<td>Decreased vocal intensity when the subjects heard their own voices amplified both in noise and no-noise condition.</td>
</tr>
<tr>
<td>Sundberg et al. (1987)</td>
<td>9</td>
<td>Effects of speaking in noise and of speaking with differently filtered auditory feedback.</td>
<td>Reduced vocal intensity when high-frequency components of auditory feedback were increased.</td>
</tr>
<tr>
<td>Laukkanen (1990)</td>
<td>41</td>
<td>Reading loud with (1) own voice in headphones, (2) filtering of the voice, (3) masking noise in the headphones, (4) artificial frequency changing.</td>
<td>(1) and (2) decreased voice loudness; (3) increased voice loudness; (4) pitch changes.</td>
</tr>
<tr>
<td>Laukkanen (1994)</td>
<td>24 4</td>
<td>Reading aloud with and without hearing own voices. Pitch manipulation of the auditory feedback.</td>
<td>In most cases reading pitch increased during pitch-changed auditory feedback.</td>
</tr>
</tbody>
</table>

2.2.8.2. Vocal loading

Prolonged voice use is called “vocal loading”. Probably the most common consequence of vocal loading is a rise of the average fundamental frequency (F0) and sound pressure level (SPL) (Kitzing, 1979; Gelfer et al., 1991; Rantala and Vilkman, 1999; Rantala et al., 1998; Stemple, 1995; Lauri et al., 1997; Buekers et al., 1995; Vilkman et al., 1999). Additionally, spectral changes take place, e.g., after vocal loading the alpha ratio has been found to be higher for females, suggesting a change towards a more hyperfunctional voice, and lower for males, suggesting a change towards a more hypofunctional voice (Novak et al., 1991). While many researchers have found an increase in F0 and SPL, others have found no or little change in F0 after vocal loading, e.g., Garrett and Healey in female voices (1987) and Stone and Rainey in both female and male voices (1991). Differences in the results may be related to differences in the loading test (length of the test, SPL required etc.) or in the subjects. Field studies on vocal loading (Ohlson, 1988; Rantala et al., 1994; Rantala et al., 1998) have shown higher values of F0 than laboratory studies (e.g., Neils and Yairi, 1987). According to Rantala et al. (1998), this difference in average F0 could amount to 69Hz for a subject. The values obtained in the laboratory
were within the limits of mean F0 reported in literature (see Krook (1988) for further review). However, the F0 values obtained in the field results exceeded those limits. Reasons for higher F0 in field studies are most likely related to higher SPL when one is speaking to a larger audience in a larger room, and to communicative factors.

2.2.8.2.1. Warm up
The initial stages of vocal loading are known as “vocal warm-up”. Vocal warm-up occurs approximately during the first half hour of speech, when vocal loading does not exceed the vocal capacity of the subject (Sherman and Jensen, 1962). It has been hypothesized that during vocal warm-up blood circulation in the vocal folds is improved in order to retain good function and viscosity (Sundberg, 1984, p193). Titze (1984) hypothesizes that slight edema due to vocal loading may cause lowering of viscosity. However, increased edema due to prolonged loading may cause the vocal folds to move less regularly resulting in impaired voice quality with roughness. A warm-up period is considered to be beneficial for the voice. Subjects feel that the voice sounds stronger and is better adjusted and they also feel more alert and energized (Scherer et al., 1987; Sherman and Jensen, 1962). For review of postulated effects and mechanism of vocal warm up see Vintturi (2001), p31. Laukkanen et al. (1998) found a decrease in glottal resistance after a minute of phonation on certain vocal exercises. This may either indicate a warm-up effect or a change in phonatory setting due to the exercises.

2.2.8.2.2. Vocal fatigue
If vocal loading is sustained over a long period or if it is excessively strong it may lead to vocal fatigue. Sapir et al. (1993) describe vocal fatigue as “voice tires easily when talking or singing” and it is described by Gotaas and Starr (1993) as “a problem that begins to occur as the speaking day progresses, is most evident at the end of the day, and usually disappears by the following morning”.

Vocal fatigue results in negative changes in vocal quality and is identified by a variety of symptoms. According to Scherer et al. (1987) vocal fatigue includes “vocal quality changes, vocal limitations, deterioration of vocal control, discomfort in various parts of the body, and changes in laryngeal tissues”. However, it has been found (Laukkanen et al., 2001) that perceived vocal fatigue does not correlate well with subjects’ sensations of fatigue, which are experienced as various symptoms in the throat. According to Colton and Casper (1990, p37) signs that may be associated with the symptoms of vocal fatigue can be defined as a) perceptual (i.e., voice becomes monopitched, tensed, breathy or hoarse), b) acoustic (phonational range is restricted and variability of fundamental frequency is reduced), c) laryngoscopic (variations of vocal fold approximation, tissue changes, e.g., nodules, muscle tension or normal appearing larynx) or d) physiological (increased airflow or inadequate closed time). Finally, muscle imbalance can be noticed.

The symptoms of vocal fatigue may be caused by:
a) Tiredness of either the laryngeal or the respiratory muscles (Titze, 1994, p323; Brodnitz, 1971). Vocal fatigue is thus attributed to fatigue in the laryngeal muscles
caused by strenuous use of the voice, resulting in loss of the lowest pitches and a rise of the comfortable pitch (Titze, 1994). Forchhammer (1974) describes how, like any other muscles in the body, the laryngeal muscles can get tired. But this fatigue is not organically detectable and can be detected only when voice production breaks down.

b) **Hyperfunctional voice use.** It is also hypothesised that vocal fatigue may be caused by lack of balance between the respiratory support and laryngeal muscle effort (Sander and Ripich, 1983), excessive use of high pitch (Stone and Sharff, 1973), excessive use of high SPL (Zagoruiko and Tambovtsev, 1982) or decreased airflow (Kostyk and Rochet, 1998).

c) **Phonation time.** The results of Rantala and Vilkman (1999) suggested that increased F0 time is a bigger risk factor for vocal fatigue than increased F0. Phonation time for preschool and elementary school teachers has been found to be three times longer than for office workers: the average of the phonation time for 8 hours was 95.2±13.6 min for the preschool teachers, 103.6±28.0 min for the elementary school teachers and 33.0±13.6 min for the office workers (Masuda et al., 1993).

d) **Loss of blood circulation** through the tissue because of internal pressure of the muscle tissue (Titze, 1994, p323).

e) **Straining** of laryngeal ligaments, joints and membranes (Titze, 1994, p323).

f) **Locked cricothyroid visor.** Harris and Lieberman (1993) stated that the cricothyroid visor could not relax after extensive voice use and remained tightly closed and even if the patient was not actually voicing the muscular effort in the larynx stayed maximal all day.

g) **Changes in tissue viscosity** of the vocal folds (Verdolini-Marston et al., 1990; Titze 1994, p323; Titze, 1989). When the tissue viscosity of the vocal folds increases it makes it harder for the vocal folds to maintain vibrations because of increased internal friction. This may result from dehydration as mechanical energy is dissipated into heat when tissue vibrates. More power is dissipated at high notes than low notes so voice use at high notes poses special problems with vocal fatigue (Titze, 1994 p 325) Verdolini-Marston et al (1990) demonstrated how the phonation threshold lowered with higher level of hydration.

f) **Lesions** in vocal fold tissue (Scherer et al., 1987; Sonninen, 1974; Gray et al., 1987). Strenuous phonation increases the risk for vocal fatigue, which in turn can lead to pathological changes in the vocal fold tissue (Scherer et al., 1987; Mann et al., 1999). Gray (1991) showed that the basement membrane zone (BMZ) in the superficial layer of the vocal folds can be at risk of damage due to vibratory stress under vocal load.

The consequence of damage is often a dysphonic voice. In addition to causing varying degrees of inconvenience to the voice patient him/herself, dysphonia may have a negative impact on message transfer in communication (Greene and Mathieson, 1991). Various investigations have shown how dysphonic voices lack intensity, range and normal frequency distribution (Gramming, 1988; Kitzing and Åkerlund, 1991; Hirano et al., 1991). Changed vibratory patterns because of increased stiffness, lesions or nodules in the vocal folds, lack of vocal fold closure or over-adduction of the vocal folds change the voice quality, and the voice becomes hoarse, husky, raspy, breathy or harsh (Martin, 1987; Siegert, 1965). Additionally, F0 and SPL often become lower than normal in diseased voices (Hirano et al., 1991; Gramming, 1991).
However, it appears that there are individual differences in levels of voice endurance, so not all voice users experience voice problems. This is in part due to physiological differences between individuals or as Colton and Casper (1990, p79) describe, “Each individual larynx has a physiological limit that varies not only from person to person but also intra-individually as influenced by numerous factors”. Fawcus (1991) points out that some people tolerate vocal exertion better than others. She established that some people became temporarily hoarse after using the voice against a high intensity background noise, while other people did not. In a vocal loading test (Vilkman et al., 1999) females were able to produce their loudest voice in the last loading sample of a day, which the researchers suggested could not point to any weakness in laryngeal or respiratory muscles. The results may though indicate that the loading was not sufficient to cause fatigue. It is also known that genetic factors influence voice quality but research into this is still scant. Sataloff (1993) asks an interesting question - “To what degree do density, size, twisting architecture (sic) vary from person to person, and what effect do the details of the connective tissues framework have on function?” (p26). He asserts that if responses were available to such questions it would be possible to identify high risk groups for vocal fatigue and assist them in preventative measures.

Well-trained voices have greater SPL and greater F0 range in speech than untrained speakers (Awan, 1993) and show less manifestation of vocal fatigue (Novak et al., 1991; Gelfer et al., 1991). Scherer et al. (1987) demonstrated how a trained voice endured longer than an untrained voice. Currently, it looks as if it is possible to increase endurance by vocal training, possibly due to adaptation of the vocal fold tissue. However, there is also a possibility that people with better vocal fold tissue are more interested in training their voices and thus all the differences between trained and untrained voices are not necessarily attributable to the effects of training.

2.2.9. Risk factors for vocal fatigue

If we look at table 4 showing some risk factors associated with vocal loading in professional voice users, it can be seen that teaching leaves the teacher open to many work-related risk factors. Some of the risk factors will be addressed in more details in chapters 2.2.9. and 2.3.
Table 4: Some voice-dependent risk factors in voice professions. Modified from Vilkman (2000).

<table>
<thead>
<tr>
<th>Work-related</th>
<th>Individual factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vocal loading (speech and song)</td>
<td>Weak voice</td>
</tr>
<tr>
<td>Stress</td>
<td>Poor technique</td>
</tr>
<tr>
<td>Poor working posture</td>
<td>Poor voice habits</td>
</tr>
<tr>
<td>Inadequate treatment of early signs</td>
<td>Personality</td>
</tr>
<tr>
<td>Air quality, dryness, dust</td>
<td>Respiratory diseases</td>
</tr>
<tr>
<td>Poor room-acoustics</td>
<td>Smoking</td>
</tr>
<tr>
<td>Background noise</td>
<td></td>
</tr>
<tr>
<td>Long distance between speaker and listener</td>
<td></td>
</tr>
</tbody>
</table>

2.2.9.1. Intensity of speech

As to risk factors, the main hazard can be considered to be prolonged use of the voice itself (Vilkman, 2001, p129), which is related to the type of phonation used and the amount of vocalisation required during a working day. Speaking to a large group or over a large distance or against background noise requires higher SPL. According to Webster (1979), increase in SPL of speech is as much as 6 dB for every 10 dB increase in noise level if it is important for each of the talker’s words to be understood. Van Summers et al. (1988) have presented results showing that F0, SPL and duration of speech sounds increase in noise; furthermore, spectral tilt decreases. Raised F0 is both a consequence of increased SPL and a way to raise SPL further. Increased adduction is related to raised SPL - and also to the aim of improving message transfer in noisy conditions. By increasing adduction the overtones get stronger, which improves the realisation of formants.

According to Jing and Titze (1994) the force with which the vocal folds collide increases as a function of F0, SPL and adduction. In hyperfunctional voices adduction is high. This means higher mechanic loading on the vocal fold tissue. Such strenuous phonation increases the risk for vocal fatigue, which in turn can lead to pathological changes in the vocal fold tissue (Scherer et al., 1987; Mann et al., 1999). On the other hand, raising the SPL does not necessarily lead to vocal fatigue according to Neils and Yairi (1987) and Stone and Sharf (1973).

2.2.9.2. Subject and grade taught

Certain groups of teachers seem to be at greater risk of developing voice problems than others. Buekers (1995), Smith at al., (1998 (b)) and Verdolini-Marston (2001) have reported that teachers of physical education and sport may be at greater risk of developing vocal symptoms than other teachers. Because of the nature of their work and their working environment these teachers face great vocal demands as they often have to use their voices in large, echoing sports halls, and outdoors where there is no acoustic feedback. Additionally, teachers of physical education exert a greater vocal effort than
other teachers because of background noise during games or because they are required to speak while doing some gymnastic activity. According to Buekers et al. (1995), sports instructors used SPL levels of 72-78 dB during approximately one third of their phonation time. Vocal symptoms have been found to be common among female army instructors (Sapir et al., 1992) and aerobic instructors (Heidel and Torgerson, 1993) as well.

Other researchers have identified music teachers as particularly prone to develop vocal symptoms (Fritzell, 1996), probably because of extended voice use at higher pitch and higher intensity than in speaking. Still others claim that preschool teachers may be under the greatest risk of developing vocal symptoms (Fritzell, 1996; Unger and Bastian, 1981; Siegert, 1965). It is well known that preschool teachers have to work in circumstances where the background noise from children is particularly great. Sala et al. (2001) found in a study on the prevalence of voice disorders among preschool teachers and nurses that approximately 50% of the teachers had voice disorders, compared to 27% among the nurses.

2.2.9.3. Gender

In most western countries women form the majority of the teaching profession. This could partly explain why so many teachers complain of voice problems, as according to research results females are more likely to report voice problems. Smith et al. (1998 (a)) pointed out that 38% of 280 female teachers reported voice problems compared with 26% of 274 male teachers. Fritzell (1996) reported that 76% of teachers seeking medical help because of voice problems were females. Russel et al. (1998) stated that females seem to be twice as likely to suffer from voice problems as males.

The reason may not lie in any gender effects on personality (e.g., women more willing to seek help) but in gender differences in the structure of the vocal organ. There are good reasons to suggest that female vocal folds are more prone to develop vocal symptoms than male vocal folds (Bridger and Epstein, 1983; Russel et al., 1998; Herrington-Hall et al., 1988; Fritzell, 1996; Lauri et al., 1997; Goldman et al., 1996; Alku and Vilkman, 1996; Buekers et al., 1995). Because of the smaller larynx, the fundamental frequency in female voices is considerably higher than in male voices i.e. the vibrations of the vocal folds are more rapid. Rantala et al. (1994) found that teachers' vocal cords vibrated during 15 - 40% of the teaching time. Vilkman (2000) calculated that a female elementary school teacher used 1,000,000 vibrations per day, based on the assumption that phonation time accounted for 30% of the teaching time (5 x 45 minutes per day). Conversely, a male speaker would use only half the number of vibrations of the vocal cords due to lower F0 (Vilkman, 2000).

Approximately two thirds of patients with nodules are females (Herrington–Hall, 1988). The reasons are assumed to be rooted in gender differences in the vocal tissue, as well as in laryngeal structure. There is a greater percentage of collagenous fibres in the male vocal folds than in the female (Hirano, 1983), which could make the male vocal folds
more enduring. Female vocal tissue may be slightly stiffer than male vocal tissue (Titze, 1989). However, according to Titze (1989): “there is no great difference between males and females in the type of tissue that is in vibration…. thus it is conceivable that hormonal factors and edema would have a significant effect on vocal tissue viscoelasticity”. It has been found that the vocal fold tissue contains hormone receptors and that these receptors vary according to age and gender of the subjects (Newman et al., 2000). Furthermore, according to Dejonckere (2001) the average number of glands and the amounts of glandular tissue are higher in males than in females; the glands and goblet cells help to lubricate the surface of the larynx. In Vintturi et al’s study (2001) females reading aloud in low humidity (25±5%) reported more subjective symptoms than males. Females may therefore be more adversely affected by low air humidity than males.

Additionally, female voices tend to become hyperfunctional more often than male voices, resulting in an increased SQ (speed quotient) and decreased CIQ (closing quotient) values as a response to vocal loading (Lauri et al., 1997). This has been considered as a risk factor because of increased collision force (Titze, 1989; Jiang and Titze, 1994).

2.2.9.4. Smoking, allergy and respiratory infections

Edema is considered to be a likely effect attributable to smoking, especially on the vibrating edge of the vocal folds. With continued smoking the mass of the vocal folds increases, which results in changes in the vibratory pattern of the vocal folds. It has been documented that smokers have lower fundamental frequencies than non smokers (Stoicheff, 1976; Comins,1990; Murphy, 1987).

Allergic reactions or respiratory infections in the upper respiratory tract can produce hoarseness or even complete loss of voice (e.g., Boone, 1991). The loose and pliable superficial layer of the vocal folds vibrates most markedly during phonation. It becomes stiffened by laryngitis (inflammation of the vocal folds and larynx). Chronic laryngitis resulting from e.g., long-term vocal abuse may lead to persistent inflammation eventual leading to thickening of the vocal folds. Impairment of the voice and vocal fold tissue is prone to impair message transfer. This leads to a need to raise effort. Unfortunately, impaired vocal fold tissue is also probably more vulnerable to fatigue and tissue lesions (Colton and Casper, 1990 p99). Gotaas and Starr (1993) found that teachers with allergic conditions suffered more from vocal fatigue than unaffected colleagues.

2.2.9.5. Hearing loss

Auditory feedback mechanism is essential for monitoring and controlling speech. It has been shown that voice intensity increases when masking has been employed (Lane and Tranel, 1971; Chang – Yit et al., 1975). Speakers who are partly deaf have less control over their voices, which may lead to deviations in pitch and timbre. Hearing problems typically result in the use of higher intensity F0 and increased adduction. This means more loading to the vocal folds. Conversely, Gotaas and Starr (1993) pointed out that teachers who suffered from vocal fatigue had more hearing loss.
2.2.9.6. Stress

A commonly held opinion is that anxiety can cause voice problems (Forchammer, 1974; Aronson, 1985; Boone, 1991; Raven, 1993; Kitch and Oates, 1994; Freidl et al., 1993). Boone (1991) pointed out that stress can be physical or situational or a combination of both. It can be found under certain circumstances in all occupations although stress is more inherited in some occupations than others. He also listed the twenty most common symptoms of stress in the voice: breathy voice, double voice, dry mouth and throat, harshness, high pitch, hoarseness, lifting up of larynx, loud voice, low pitch, monotone, no voice (aphonia), neck or throat pain, pitch breaks, shortness of breath, strained voice, throat clearing, tight voice, traumatic laryngitis, voice breaks and weak voice. Kyriacou and Sutcliffe (1978) investigated stress amongst 257 teachers who worked in sixteen medium-sized, mixed comprehensive schools in England. It was found that 20% of the teachers considered the job very stressful or extremely stressful, and they complained about being exhausted and frustrated. This is much in line with the findings of Sapir et al. (1993) and Raven (1993), who found that psychological stress is common amongst teachers. In Kyriacou and Sutcliffe’s (1978) investigations the levels and nature of stress seem to be first and foremost dependent upon the personality of the teacher. There appears to be no link between the biographical characteristics of the teachers (sex, qualification, age, length of teaching experience and position held in the school) and self-reported teacher stress, according to Kyriacou and Sutcliffe’s results. On the other hand, a more thorough study of the ergonomic conditions under which the teacher worked might reveal that the job itself may also be a substantial source of stress.

2.2.9.7. Posture

Little attention has so far been given to possible effects of posture on loading-related vocal symptoms. Bodily stance at work is too often a matter in which workers have little choice, and for teachers there are difficulties arising from the fact that they spend much of their time standing and leaning over pupils’ desks. It seems plausible to suggest that a certain balanced posture and head position would give the most ergonomic conditions for muscle function also related to voice production.

It is obvious that posture affects the type of breathing. Iwarsson and Sundberg (1998) found connections between high lung volume and a lower position of the larynx. Furthermore, they indicated that the vertical position of the larynx has an influence on the F0 of the voice. Sundberg et al. (1987) found that there is a connection between a lowered laryngeal position and flow phonation (p84): “In flow phonation the amplitude [of the AC flow] is high, the closed phase long, [subglottic] pressure moderate, sound level high, and glottal area wide”. Flow phonation, in turn, has been regarded as optimal from the point of view of message transfer and also from voice hygiene. Vintturi et al. (2001) found that during vocal loading, male voices demonstrated a greater change towards more pressed phonation when the subjects were in a sitting position than was found in phonation if they were standing. Interestingly these changes were not found in females voices. The position of the head is also of importance for voice production. Sonninen (1968) found that holding the head of the subjects immobile while singing caused increased lengthening of the vocal chords due to the activity of sternothyroid,
sternohyoid and thyrohyoid muscles and the muscles of the floor of the mouth attached to
the hyoid bone. These findings show how the head position affects the contraction of
certain muscles in the laryngeal region which also may have effects on voice production.

2.3. THE CLASSROOM: EFFECTS WHICH MAY HARM THE
TEACHER'S VOICE AND DIMINISH TEACHING EFFICIENCY

2.3.1. Environmental effects in general

Martin (1994) found that 44% of 95 teachers blamed environmental factors for their
voice problems. In Jonsdottir's (1997) study a correlation was found between teachers'
complaints of having a dry throat, pitch breaks and a lump in the throat and finding
internal air quality bad. Many teachers have to work in poor surroundings such as
overheated and stuffy buildings, with fumes from various noxious substances, dusty
classrooms, poor air-conditioning, low oxygen levels, poor humidity, and poor acoustics
with too long or too short reverberation time. Any one of these factors can lead to vocal
abnormality (Colton and Casper, 1990; Sataloff, 1994; Hemler et al., 1995; Vilkman,
1996; Verdolini – Marston et al., 1990; Pekkarinen, 1988; Sala et al., 2002).

2.3.2. Air humidity

Lubrication is an essential element if the vocal folds are to be flexible under phonation.
Sihvo (1997) found that the dynamic range of the voice range profile (VRP) decreased in
low (25%) and increased in high (65%) air humidity. This is in line with the results by
Verdolini-Marston (1990) which showed that more subglottal pressure was needed for
phonation in dry (30-35%) than wet (85 -100%) conditions. It appears that a high ambient
air humidity is beneficial for voice production. Andrews (1995) stresses that dry vocal
folds become more easily irritated than folds with sufficient lubrication, indicating that
adequate humidity is required for effective vibration of the vocal folds. Currently, the
Occupational Health and Safety Executive in Iceland (Vinnueftirlit Ríkisins, 1990)
considers that a humidity level of 35% is beneficial in classrooms. Sundell (1994) pointed
out that low humidity, poor ventilation and too high temperatures caused evaporation.
The formation of dust particles can also lead to Sick Building Syndrome, which amongst
other symptoms results in dryness of the mouth and throat. Because of the severe weather
conditions in countries such as Iceland it is difficult to change the classroom air. The
measurement taken by the Vinnueftirlit Ríkisins (Administration of Occupational Safety
and Health in Iceland) pointed to the fact that the air in Icelandic classrooms can be so
dry that it may be difficult to use the voice in them without giving risk for rise to vocal
strain. Therefore there is a possibility that Icelandic teachers live and work in too dry air
conditions, increasing the risk of voice disorders due to drying of the mucus membranes
of the vocal apparatus.
2.3.3. Poor acoustics and classroom noise

The classroom must have good acoustics if the pupils are to hear clearly what the teacher is saying. In fact, poor acoustics and classroom noise are probably the factors most commonly identified as impairing the intelligibility of speech in classrooms (e.g., Berg, 1993; Crandell and Smaldino, 1995 (b); Crandell, Smaldino and Flexer, 1995). Also they are probably the most common external factors highlighted as having a damaging effect on teachers' voices (e.g., Markides, 1986; Pekkarinen and Viljanen, 1990; Vilkman, 1996). Self-reported questionnaire responses on poor acoustics and voice problems have shown that they are significantly associated (Jonsdottir, 1997; Morton and Watson, 1998). Information from 1200 teachers indicates that noise affects teachers' performance, in that they state that there is a direct link between classroom noise and fatigue (Ko, 1979). In Hétu, Truchon – Gagnon and Bilodeau's (1990) findings, 54% of classroom teachers and 77% of physical education teachers stated that noise commonly caused communication problems in their respective work environments, in contrast to 9% of office workers.

There are four principal factors which are considered to affect classroom acoustics and, thus, the teachers' vocal load. They also affect the student’s ability to hear the teacher's instructions and explanations (e.g., Crandell and Smaldino, 1995 (a)):

- Background noise
- The signal to noise ratio
- Reverberation time.
- Teacher-student distance

These factors will be discussed in what follows.

2.3.3.1. Background noise in classrooms

It is recommended that the A-weighted sound level in work spaces where speech communication is essential should not exceed 62 dB(A) to permit satisfactory communication at a distance of 2 m (Webster, 1979). Classroom noise is derived from activities inside and outside the classroom. Berg (1993) stresses that for students' effective listening, noise levels should not exceed 40-50 dB(A) in occupied classrooms; in unoccupied classrooms the noise level should be set at below 35 - 40 dB(A). This assertion is confirmed by the findings of the American Speech-Language-Hearing Association (ASHA) which recommends that ambient noise level for optimum listening conditions in classrooms should not exceed 30-35 dB in unoccupied classrooms (1995). McCroskey and Devens (1975) found that only one of nine elementary school classrooms met these acoustical recommendations and in Crandell and Smaldino’s (1994) findings none of 32 classrooms met recommended criteria. Smaldino and Crandell (1995 (b)) stated that noise levels in classrooms are in general 10-15 dB higher than recommended standards. Some examples show that conditions may be much worse than this. Sanders (1965) found that the noise level in one kindergarten was above 65 dB for 71% of the time and above 70dB for 25% of the time.
Moodley (1989) studied noise levels in 40 English schools over a period of several months. According to his results noise levels in occupied classrooms were unacceptably high (table 5):

Table 5. Average noise level (dB (A)) in classrooms at three different education levels (Moodley, 1989).

<table>
<thead>
<tr>
<th></th>
<th>Mean dB(A)</th>
<th>Range dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nursery schools/classes:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empty classrooms</td>
<td>42.5</td>
<td>38.4 – 48.5</td>
</tr>
<tr>
<td>Class at work</td>
<td>75.0</td>
<td>65.0 – 85.0</td>
</tr>
<tr>
<td>Primary schools/classes:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empty classrooms</td>
<td>46.6</td>
<td>35.0 – 64.2</td>
</tr>
<tr>
<td>Class at work</td>
<td>65.3</td>
<td>47.5 – 81.3</td>
</tr>
<tr>
<td>Secondary schools/classes:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empty classrooms</td>
<td>45.3</td>
<td>35.0 – 62.7</td>
</tr>
<tr>
<td>Class at work</td>
<td>64.5</td>
<td>52.4 – 75.2</td>
</tr>
</tbody>
</table>

The results tally with the findings of various other researchers who have reported 55 - 77 dB(A) average noise levels in occupied classrooms (Marcides, 1986; Airey, 1998; Berg, 1993; Sanders, 1965; Berg, 1993). Additionally, according to Hay and Comins (1995), high-pitched voices, raised to be heard over the noise from children, merge into the background noise in a classroom.

In Laukkanen's (1990) study on the effect of manipulated auditory feedback, subjects increased their loudness while reading aloud with dark noise (low-pass filtration at 600 Hz), bright noise (high-pass filtration at 600 Hz) and white noise in headphones. According to Crandell and Smaldino (1995) (a) low-frequency noise appears to be the predominant noise in classrooms and has a greater effect on speech recognition than high-frequency noise. One may suppose that classroom noise may have a similar effect on the teacher's voice as that obtained by masking the normal auditory feedback. Lane and Tranel (1971) showed that subjects change the loudness of their voices in direct relationship with the volume of noise against which they were speaking. Thus subjects increase their voice intensity by 1 dB for every 2 dB of background noise.

2.3.3.2. Effect of ambient noise on intelligibility of speech

In the 30 dB range ranging between 23-53 dB, measured in non-reverberant quiet rooms, the vowel sounds comprise 60% of the sound energy of speech but contribute only 5% towards the intelligibility of speech. In contrast, consonants represent 5% of the sound energy in speech but are responsible for 60% of the intelligibility of speech (Florida Department of Education, 1994). Rosenberg and Blake-Rahter (1995) point out that consonants are relatively weak and short in duration and are consequently more vulnerable to the damaging effects of ambient noise than most vowel sounds. The
consonant sounds are also more vulnerable to poor acoustics as they include more high frequency energy, which is absorbed by most room surfaces. Due to upward spread of masking, the more powerful noise found in the low frequencies in classroom noise tends to mask the less powerful high frequency speech sounds (e.g., s, f, θ) that are critical for speech recognition (Rosenberg and Blake-Rahter, 1995). This is a matter for concern as low-frequency noise is assumed to be predominant in the spectra of noise found in classrooms (Crandell and Smaldino, 1995 (a)). As most of our ability to detect word differences, and ultimately to discern meaning, is derived from high frequency acoustical phonemes, pupils must be able to hear them. Indeed, Green et al. (1982) claim that approximately 50-70% of reading delays in elementary school children can be directly attributed to the effects of classroom noise. Lehman and Gratiot (1983) point out that attention and concentration in students increased when classroom noise was decreased.

Maintaining speech intelligibility seems to be possible under difficult conditions for achieving auditory feedback. Indeed, some utterances produced in noise have been shown to be more intelligible than utterances produced in quiet (Van Summers et al., 1988; Pekkarinen, 1988). It has been suggested that speakers try to maintain intelligible speech by altering their vocal production according to auditory feedback (Lane and Tranel, 1971).

2.3.3.3. Reverberation time in classrooms

Sound reflects off smooth surfaces such as walls, furniture, ceilings and windows. The reflection paths in a classroom can be many and each of these reflections will arrive at the listener within a very short time of each other. These reflections are called reverberant sound. Reverberation time (RT) refers to the amount of time it takes for a steady sound to decay 60 dB from its initial offset. The longer the reverberation time is, the more difficult it is to hear clearly. Large rooms with high ceilings, bare walls and bare floors, as many classrooms are, tend to have too long a reverberation time. Speech recognition in adult listeners is not reduced until RT exceeds approximately one second (Gelfand and Silman, 1979).

The American Speech-Language-Hearing Association (ASHA) recommends that RT shall not exceed 0.4 second for optimal listening conditions in classrooms. Recommended levels for reverberation time in unoccupied classrooms in the US, UK, Iceland and Finland range from 0.4 to 0.9 s. For young listeners reverberation time must not exceed 0.4 s if they are to obtain optimum communicative efficiency (Finitzo-Hieber, 1988; Crandell, 1991; Finitzo-Hieber and Tillman, 1978). However, the range of RT for unoccupied classroom settings is typically reported to be from 0.4 to 1.5 seconds (Crandell, 1991; Crandell and Smaldino, 1994; Finitzo-Hieber, 1988; Berg, 1993). For further information, see table in MacKenzie (1998).

2.3.3.4. Signal to noise ratio in classrooms

Signal to noise ratio (S/N ratio) is the relationship between the desired auditory signal and all unwanted background sound. It has been recommended that S/N ratio in children's learning environments should exceed 15 dB for maximum speech recognition (ASHA,
1995; Crandell, 1991; Finitzo-Hieber, 1988). For disabled children the ratio should be larger, at least 17-20 dB (Leventhall, 1998). In other words, the teacher’s voice (the auditory signal) has to be 15-20 dB stronger than the classroom noise. A lower S/N ratio has been shown to lead to difficulties in speech recognition (Crandell and Smaldino, 1995 (b)). However, according to Sanders (1965) S/N ratio in classroom condition is frequently less, even as poor as 1 - 5 dB.

Table 6 shows word recognition by children in varying S/N conditions (Finitzo-Hieber and Tillman, 1978). The evidence indicates that children with normal hearing are able to understand only 71% of what is being said in 6 dB S/N condition when reverberation time is 0.4 s. Amongst children with hearing impairment the figure is 52%. Children with normal hearing achieve only 54% monosyllabic word discrimination in commonly reported classroom conditions (S/N +6 dB, RT 1.2 s). Moncur and Dirks (1967) found that adults with normal hearing have the ability to recognise approximately 80% of monosyllabic words in 0.9 s RT conditions. Crandell and Smaldino (1995 b) state that in general speech recognition in adult listeners with normal hearing is not significantly affected until the speech and noise are at equal intensities.


<table>
<thead>
<tr>
<th>Reverberation time(s)</th>
<th>Signal to noise ratio (dB)</th>
<th>Scores of normal hearing children</th>
<th>Scores of hearing impaired children</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>+12</td>
<td>83%</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>+ 6</td>
<td>71%</td>
<td>52%</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>48%</td>
<td>28%</td>
</tr>
<tr>
<td>1.2</td>
<td>+12</td>
<td>69%</td>
<td>41%</td>
</tr>
<tr>
<td></td>
<td>+ 6</td>
<td>54%</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>28%</td>
<td>11%</td>
</tr>
</tbody>
</table>

It is suggested that the sum effect of reverberation and noise adversely affects speech recognition to a greater extent than when both effects are taken separately (Berg, 1993; Pekkarinen, 1988; Johnson, 2000).
2.3.3.5. Teacher – student distance

Classrooms are usually large, and sound loses its force according to the “inverse square law” (i.e., sound level decreases 6 dB for every doubling of distance from the sound source in a non-reverberant field) The sound which travels straight from the source to the listener’s ear is called “direct sound”, and for the best understanding of a message a substantial proportion of the acoustic energy of the voice must be received by the listeners as direct sound.

2.3.3.6. Critical distance

Because of the inverse square law, the direct sound field in a classroom is dominant only at distances close to the teacher (Crandell and Smaldino, 1995 (a)). Indeed, Harris (1979) stated that for ideal speech communication to take place the distance between the teacher and students should be 3 – 4 feet (about one meter) only.

The “critical distance” is defined as the distance where the indirect or reverberant field begins to dominate the listener’s environment. According to Crandell and Smaldino (1995 (b)) the critical distance in a classroom of 150 m³ in size with RT of 0.6 s would be approximately 3 meters from the teacher; “thus many, if not most, children in a classrooms will be in the indirect sound field”. Leavitt and Flexer (1991) used Rapid Speech Transmission Index (RASTI) to estimate speech perception in a classroom. In RASTI, speech-like signals are used in ways that can be related to speech perception. The results pointed out that 83% of the speech energy was available to the listeners in the front seat but decreased to 55% in the centre of the back row. Crandell and Bess (1986) examined the speech recognition of 5-14 years old children in classroom environment with S/N ratio 6dB and RT 0.45 s. The mean speech recognition scores of 95, 71, and 60% were obtained at 6,12 and 24 feet (1.83, 3.66 and 7.32 meters, respectively). Crandell and Bess (1986) used monosyllabic words in their investigation into speech recognition of 20 children with normal hearing, aged 5-7 years old, in listening circumstances where S/N ratio was 6dB and RT 0.63 s. Mean word recognition scores of 82%, 55%, and 36% were obtained at 6, 12, and 24 feet, respectively. This means that pupils sitting in the middle of a class or further back may not be able to hear enough of what the teacher is saying to understand its content. However, Pekkarinen (1988, p57-76) found that sentences were perceived better than words in reverberant classroom conditions, so young children may recognise classroom speech better than the figures quoted above may suggest.

2.3.4. Students’ ability to understand speech in the classroom

It is estimated that young children may spend as much as 60% of their school day involved in the listening process (Rosenberg and Blake-Rahter, 1995). According to Crandell et al. (1995) the child does not generally reach adult-like performance on recognition tasks in noise or reverberation until approximately 13-15 years of age; in particular, the ability to identify consonants in such conditions may not mature until late
teenage years (Johnson et al., 2000). Adult listeners need fewer auditory clues to understand meaning, as they have more pre-existent knowledge and can thus reconstruct language from fewer phonemes. Young listeners may therefore not be as effective listeners as adults, especially in combined conditions (Pekkarinen, 1988; Johnson, 2000). According to information from the Acoustical Society of America young listeners require 2-3 dB higher S/N ratio than adults in conditions where there is background noise in order to obtain the same level of communication (Mackenzie, 1998). The children who are worst served by a poor acoustical environment, and need the best possible environmental conditions for listening, are those with handicaps, e.g., hearing problems, language disorders, developmental disabilities, articulation disorders, learning disabilities, or those learning through the medium of a language which is not their mother tongue (Crandell et al., 1995; Elliot, 1982; McCormick and Schiefelbusch, 1984; Flexer, et al. 1990). Such children have a lowered ability to identify the desired acoustic signal and demonstrate poorer speech recognition in classroom noise than children with normal learning abilities.

### 2.3.4.1 Hearing problems in children

Probably the largest group of handicapped children are those with temporary hearing loss due to otitis media. Crandell et al. (1995) state that between 76% and 95% of all children experience at least one episode of otitis media with effusion by the age of six years. Additionally, one third of all children suffer from persistent otitis media during their first 3 years of life, a vital time for speech and language development. According to Leventhall (1998), an increasing number of children are experiencing mild temporary hearing loss because of otitis media. He also states that it is estimated that 25-30% of children in kindergarten and first grade will not be able to hear normally on any given day. Hull (personal contact, 2000) has also pointed to an increase in hearing impairment amongst young high school students; he suggests that about 70% of these students may suffer from the early stages of hearing loss. ASHA studies (1995) have shown that 13% of a representative sample of children between the age of 6 and 19 had high frequency hearing loss and 7% low frequency loss of 60 dB or more. Dobie and Berlin (1979) showed that mild (20 dB) conductive hearing loss in children can limit their ability to understand brief utterances and/or interpret high frequency stimuli, particularly if the listening environment is not favourable. As can be seen from table 6, children of 8-12 years with hearing impairment obtained only one third accuracy in monosyllabic word discrimination in classrooms where the hearing conditions were S/N 6 dB and RT 1.2 s.
2.4. AMPLIFICATION IN CLASS

2.4.1. Sound field amplification systems

According to the literature, the use of amplification in classrooms for children with normal hearing seems to be virtually unknown, although amplification devices suitable for classroom purposes have existed for a considerable time. With the arrival of cordless microphones it is possible for a teacher to move around the classroom while using the amplification system. If the teacher wishes to teach an individual pupil it is possible for him or her to switch off the transmitter and so ensure that what is said is not heard by the whole class.

The equipment consists of a sender unit, made up of a cordless microphone and a radio transmitter, and a receiver unit consisting of a receiver and an amplifier. The microphone, worn on the chest or on a headband, is linked with a portable radio transmitter which can be clipped to, e.g., a belt. The receiver is linked to one or more amplifiers which amplify the sound to the level required. The amplifiers can be either portable, fastened to the wall or freestanding on the floor.

The cost depends on the quality and size of the equipment. Flexer et al. (1995) stated that if a high quality permanent sound system was installed (e.g., as used in theatres and public halls) the cost would run to thousands of dollars, whereas in school session 2001-2002 in Iceland, the cost of providing amplification equipment was between 1046 and 1395 euros per classroom.

2.4.2. The advantages and disadvantages of using sound field amplification

Until now it has not been the practice to amplify the teacher’s voice in normal circumstances. However, a number of studies have investigated the effects of sound field amplification for non-handicapped children in classrooms. Qualitative results from questionnaires indicate that teachers appreciate the value of amplification. Indeed, teachers who have had the opportunity to make use of sound field amplification choose that in preference to other equipment such as overhead projectors, televisions, computers and filmsstrip projectors (Allen, 1993). Evaluations by teachers indicate that amplification reduces vocal strain and voice fatigue (Sarff, 1981; Gilman and Danzer, 1989; Rosenberg et al., 1994). As can be seen in table 7 amplification seems to reduce vocal strain and vocal symptoms.
Table 7: A summary of studies on auditory feedback when using amplification.

<table>
<thead>
<tr>
<th>Author</th>
<th>Subjects</th>
<th>Method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chang – Yi et al. (1975)</td>
<td>5 1</td>
<td>Sidetone* amplification effect assessed over 5 days of testing.</td>
<td>Decreased vocal intensity.</td>
</tr>
<tr>
<td>Roy et al. (2002)</td>
<td>15</td>
<td>Use of Chatter Vox portable amplification device for several weeks.</td>
<td>Reductions in jitter, shimmer and Voice Handicap index scores.</td>
</tr>
<tr>
<td>Sapienza et al. (1999)</td>
<td>4 6</td>
<td>SPL examined during lecture in classrooms with and without amplification.</td>
<td>Amplification lowered SPL significantly (mean decrease 2.42 dB).</td>
</tr>
</tbody>
</table>

(* Sidetone amplification = when the voice is amplified, the subject typically lowers his/her voice)

Additionally, in Sarff’s study (1981) with pupils aged 10 to 12, conducted over a period of three years, amplification enabled teachers to teach with fewer hesitations, repetitions or interruptions to the flow of the lesson. This is in line with Allen and Patton’s (1990) results which indicated that teachers using amplification needed to repeat themselves less often.

To the best of my knowledge, up till now there has been little quantitative information about the effects of sound field amplification in teaching on such vocal parameters as SPL, F0 and spectrum in teachers’ voices. It is known that speakers decrease their vocal intensity by 1 dB for every 2 dB of amplified vocal feedback (Lane and Tranel, 1971). Sapienza et al. (1999) demonstrated that the use of amplification significantly lowered SPL (mean decrease 2.42 dB) in 10 teachers’ voices while lecturing for 15 minutes in an unoccupied classroom. In Rosenberg and co-workers’ (1994) study on 855 students in 40 classes (20 amplified and 20 control) teachers using amplification showed an average gain of 7.52 dB and in Flexer et al’s (1990) study amplification increased the intensity of the teacher’s voice by 10 dB.

Flexer et al. (1995) state that the goal of a sound-field amplification system is to provide an even and consistent S/N ratio improvement of approximately 10 dB throughout the learning area. Research has demonstrated the efficacy of sound field amplification in improving students’ speech recognition, academic achievement, learning behaviour and ability to receive instruction (Sarff, 1981; Gilman and Danzer, 1989). Crandell (1994) showed that field amplification at a speaker-listener distance of 12 and 24 feet significantly increased speech perception in children for whom English was not the native language. Other findings have reached the same conclusions among students with normal hearing in classroom conditions of S/N ratio 6dB and RT 0.6 s (Crandell and Bess, 1986;
Crandell, 1993). Flexer et al. (1990) studied speech recognition of 9 developmentally handicapped children in a primary-level class. Results showed that errors in a Word Intelligibility by Picture Identification test (WIPI) dropped by approximately two thirds when amplification was used. Additionally, it was observed that the children were more relaxed and answered more quickly in amplified conditions. Flexer, Millin and Brown (1990) showed how children with developmental disabilities made significantly fewer errors in a word identification task when the teacher used amplification. Lehman and Gratiot (1983) demonstrated that a reduction in classroom noise had a significant effect in increasing concentration, attention and participatory behaviour in 9 children with developmental disabilities. Additionally, it was observed in Flexer et al’s (1990) study that the children were more relaxed and responded more quickly in the amplified condition. Findings have also shown that amplification improves the classroom behaviour of young children (Palmer, 1998; Allen and Patton, 1990). Indeed, findings have indicated that young children make much more progress when amplification is used (Sarff, 1981). The disadvantages of using amplification equipment appear to lie principally in a) the failure of teachers to tune the system properly due to a lack of the required knowledge and b) an inappropriate amplification system being chosen for use in the classroom (listed below).

**Advantages**

*Summarised research results identifying the advantages of amplification systems in classrooms (Rosenberg and Blake-Rahter, 1995 p108-109)*

- Reduced vocal strain and fatigue for teachers
- Improved academic achievement, especially for younger students
- Decreased distractibility and increased on-task behaviour
- Increased attention to verbal instruction and activities and improved understanding
- Decreased number of requests for repetition
- Decreased frequency of need for verbal reinforcement to facilitate test performance
- Decreased test-taking time
- Improved spelling ability under degraded listening conditions
- Increased sentence recognition ability
- Improved listening test scores
- Increased language growth
- Increased preference by teachers and students for sound-field FM amplification in the classroom
- Improved ease of listening and teaching
- Reduced special education referral rate
- Increased seating options for students with hearing loss
- Cost-effective means of enhancing the listening and learning environment

**Disadvantages**

*Summarised research results identifying the disadvantages of amplification systems in classrooms (Flexer et al, 1995 p126)*

- Too much amplification
- An inappropriate amplification system for the classroom
- Failure to be of value in excessively noisy or reverberant classrooms
- Insufficient technical knowledge in the teacher, causing, e.g., acoustical feedback when the teacher speaks too close to the microphone, or sets the gain or the volume of the system too high.
Although results are available on both teachers' and students' reactions to the use of amplification in the classroom as well as teachers' subjective sensations, to my knowledge no results have so far been published on how amplification may affect vocal parameters during the working day.
3. AIMS

The aims of this study were threefold:
- to obtain more detailed acoustic information about the effects of amplification on speech;
- to obtain, by following the changes in speech parameters during a teacher’s working day, more information about the effects of vocal loading;
- to obtain via questionnaires information that could help to improve the amplification systems used in classrooms;

Seven questions were addressed:

To reach the first aim:
1. Does amplified and damped auditory feedback lower the average fundamental frequency (F0), and sound pressure level (SPL) in text reading? (Study I)
2. Does the use of amplification lower F0 and SPL of the teacher's classroom speech? (Study II)
3. Is there a change in vocal parameters and in perceptual voice quality when amplification is used in classrooms as compared to non-amplified conditions? (Studies IV and V)
4. Does the use of amplification in classrooms diminish the teachers' symptoms of vocal fatigue? (Study III)
5. Does the use of amplification in classrooms make it easier for pupils to follow teaching? (Study III)

To reach the second aim:
6. Is there a change in vocal parameters (F0, SPL, phonation time, long-term-average spectrum) and in perceptual voice quality during a teacher's working day? (Studies IV and V)

To reach the third aim:
7. What advantages and disadvantages of the use of amplification in classroom will be reported by the teachers and students? (Study III)
4. SUBJECTS AND METHODS

4.1. SUBJECTS

In Study I the subjects were six Finnish females (mean age 33 years) without any known voice or hearing problems.

In Study III the subjects were 33 teachers (26 females, 7 males) and their 791 students (446 females and 345 males) from three Icelandic educational institutions. The institutions consisted of a university, two schools from the Icelandic basic school system for learners aged 6 - 15, and a junior college for learners aged 16 - 20. Of the learners, 174 females and 207 males came from the basic school system, 221 females and 108 males came from a junior college and 51 females and 30 males from a university.

The average numbers of pupils in the classes were 19 (range 15 – 28) in the basic school system, 22 (range 18 – 22) in the junior college and 53 (range 33 – 76) in the university. The classrooms were of different sizes ranging from 40 m² in the basic school system to 158 m² in the university; a gymnastic hall of 175 m² was also used in the study. The mean age of the teachers' group was 45 years (range 27 – 64 years). The mean teaching experience was 16 years (range 1 – 32 years). Nine percent were smokers. Half of the teachers reported that they suffered from vocal fatigue.

In Studies II, IV and V the subjects were three females and two males (mean age 51, range 41 - 63 years) taken from the group of 33 teachers in Study III. All subjects had a long teaching experience (10 - 31 years). Two of the females taught the youngest pupils in the basic school system. The others worked in a junior college. All were non-smokers and all suffered from multiple vocal symptoms (3 or more symptoms) that mostly occurred during the term and therefore seemed to be work-related. One female suffered from asthma and allergies. Because of non-organic dysphonia, she had been given 8 voice lessons by a speech pathologist. One female suffered from a slight hearing problem. A clinical examination of each subject was performed before the experiment started. No pathological changes were found in their vocal organs.

4.1.1. Vocal symptoms of the teachers (III)

Background information was collected via 19 multiple choice questions (see Appendix 1). The subjects reported on the prevalence of their vocal symptoms on a scale of 1 – 5 (1 = Hardly ever, 2 = Seldom, 3 = Sometimes, 4 = Often, 5 = Almost always). Replies for choices 1 – 2 were interpreted as “no” and for choices 3 - 5 as “yes”). Stressfulness of teaching was rated on a scale 1 – 8, where readings for stressfulness were estimated on an ascending scale of 1 to 8. Results found that scores of 6 - 8 should be regarded as indicating stress.
Fig 3. Self reported vocal symptoms of 33 teachers.

As can be seen in fig. 3 about half of the group experienced vocal fatigue while singing and reading aloud, voice breaks while teaching and voice inadequacy in noisy situations. One third complained of hoarseness without a cold, vocal fatigue during conversation, failure of the voice to last out a teaching session and voice failure while teaching. One third complained of discomfort in the throat: dryness, tickles, lumps, sore throat.

More than half of the group (64%) reported that they experienced the symptoms while teaching. None reported on having experienced symptoms during the summer holidays. Thirty nine percent of the teachers reported they found teaching stressful.
4.2. METHODS

4.2.1. Voice samples

4.2.1.1. In laboratory conditions (I)

4.2.1.1.1. Amplified feedback

The subjects read aloud from a text consisting of 133 words without any /s/ phonemes while wearing headphones (Sennheiser HD 530II). The signal picked up by the microphone was fed through an amplifier (an extra DAT recorder (TASCAM DA 20MKII)) and fed back to the headphones so that the subjects heard their own voices louder. The subjects set the level of the amplification as they found it most comfortable to listen to. The amplification was adjusted with the phone control button of the DAT recorder by the subjects themselves. The subjects read the text twice in the morning and twice in the evening, on each occasion reading first without amplification and then with amplification. These readings were repeated on two further occasions, the intervals between the readings varying from one week to three months. In total there were thus 12 samples recorded under normal circumstances and 12 recorded with amplified feedback.

One microphone (Brüel and Kjær 4164) was at a distance of 40 cm from the subject’s mouth. A similar microphone was placed inside the headphones to record the amplified signal. The signals were calibrated (Brüel and Kjær sound level calibrator type 4230) for sound pressure level measurement. The reason for using two microphones was to study how loudly the subjects wanted to hear their voices.

4.2.1.1.2. Damped feedback

The procedure was the same for the damped feedback test as for the amplification test; the subjects recorded 12 samples under normal circumstances and 12 with amplification. Thus, for the damped feedback test the subjects recorded 12 samples under normal circumstances and 12 with foam plastic earplugs. The headphones were replaced by earplugs for the damped feedback test. The damping effect of the foam plastic earplugs varied at different frequencies, increasing gradually from 22.3 dB at 63 Hz up to 40.4 dB at 8000 Hz.

4.2.2. In field conditions (II, IV, V)

In Studies II, IV and V the recordings took place in the classrooms routinely used by the teachers in their daily work. The classrooms were on average 55 m² in size, ranging from 38 to 70 m². The length of the working day ranged from 5 lessons (each lasting 40 minutes) common in the basic school system to 9 lessons taught by one of the teachers at the junior college. From their timetables, the subjects chose for research purposes the scheduled working day which they considered to be the one which was most vocally
demanding. On that day the teacher's classroom speech was recorded in the first and last lesson, each lasting ca 35 – 40 min, first without amplification and then on the same day a week later with amplification. The subjects had used amplification in class during that week (a WL 184 lapel condenser chest microphone and an ETGS transmitter and receiver; an Anchor AN 100, or a Trace Elliott 30 Watt combined amplifier and a portable loudspeaker). The portable loudspeaker was placed on a shelf or a desk in front of the class. As the system was cordless the teacher could walk freely in the classroom, turning the system off if needed. The amplification level was chosen by the teacher. When amplified speech was recorded the subjects had 2 microphones - one chest microphone (WL 184 lapel condenser) for amplification and one (Senheisser MK 2) attached to a headset for recording at a distance of 7 cm from the mouth. The transmitter which transferred the sound from the microphone to the receiver was located on a belt worn by the teacher. The DAT recorder was carried in a bag hanging from the waist of the teacher.

4.2.3. Analyses of the speech samples

4.2.3.1. Fundamental frequency, sound pressure level (I, II,IV) and phonation time (II)

In Studies II and IV the speech material analysed consisted of three 4 minute samples taken from the very beginning, middle and end of the first and last lesson without and with amplification. F0 and SPL were measured with an analogue system (F-J electronics). Filter limits for female voices were 300 Hz and 70 Hz with a slope of 36 dB/octave. For male voices the filter limits were 200 Hz and 40 Hz. Integration time was 10 ms for SPL signal.

Analyses were made with a microcomputer (Apple Machintosh Quadra 950) equipped with three extension boards (National Instruments). By using the LabVIEW 2 graphical programming system the signal was divided into 4 different channels - two channels for the SPL of two different integration times, one for F0 and one for audio signal. The sampling rate for each signal was 5 kHz. The limits employed by the analysis program were 61 – 100 dB for the SPL and 140 – 450 Hz for females’ F0 and 70 – 250 Hz for males’ F0. The phonation time - i.e. the time during which the vocal folds were vibrating - was calculated from the F0 signal.

In Study I, F0 and SPL were measured with a computerized signal analysis system called the Intelligent Speech Analyser (ISA) developed by Raimo Toivonen (M.Sc.Eng.). The alpha ratio was calculated by dividing SPL at the range 1-10 kHz by the SPL of the range 50 Hz-1 kHz (Frøkjær – Jensen, 1976). As the alpha ratio illustrates the frequency distribution of sound energy it was used to study the acoustic quality.

Changes in F0 were transferred in semitones using the formula 39.86 x log (F0/16.35) in order to make male and female voices comparable.
4.2.3.2. Long-term-average-spectrum (I,V)

In Study V a Long-term-average-spectrum (LTAS) analysis was made with ISA. In Study I the spectrum was studied by calculating SPL at different frequency ranges with ISA. Recordings were analysed in Study I. In Study V three samples of 2 minutes duration taken from the very beginning, from the middle and from the end of the first and the last lesson of a working day (i.e. a total of 6 minutes of classroom speech) were analysed from the first and from the last lesson. Voiceless sounds and pauses were excluded automatically from the signal. Background noise was not excluded since exclusion was not regarded as necessary (see below) and would have required very strenuous and time-consuming manual editing.

SPL was calculated of the following frequency ranges with ISA or the peak amplitude of these frequency ranges was measured manually from LTAS (see Fig. 4) to describe the spectral structure numerically:

- F0 (measured mean of F0 ± 50 Hz).
- The first formant (F1) region; 300 – 1000 Hz
- 50 Hz - 1 kHz
- 2 – 5 kHz
- 5 – 10 kHz
- 1 – 10 kHz
To illustrate the sound energy distribution more clearly the differences between the SPL values of the following frequencies were calculated:

- the range of F1 and the range of F0 (F1-F0) (I)
- the range of F1 and 2 – 5 kHz region (I,V)
- the range of F1 and 5-10 kHz region (I,V)

Alpha ratio was calculated by dividing the SPL of the range 1 – 10 kHz by the SPL of the range 50 Hz – 1 kHz. (I)

To study the effect of background noise (children’s chat) on LTAS a test was made as can be seen in figure 4. As can be seen SPL in the teacher’s voice (underlined, bold) was considerably stronger than SPL in the background noise. Therefore, the background noise was ignored.

Figure 5. Top: Time-amplitude presentation of teacher’s speech (marked with underlined bold line) and background noise (children’s chat). Teacher’s speech 22 dB stronger in SPL. Middle: LTAS of a female teacher’s speech without background noise. Bottom: LTAS of the teacher’s speech with background noise (children’s chat).
LTAS analysis was performed on a sample in which the teacher spoke without background noise (black line below the time-amplitude presentation). Thereafter a LTAS was made from a longer sample in which there was classroom chat (the whole signal shown in the time-amplitude presentation). A particular section of the recording was chosen because there was particularly strong background noise in the classroom. It can be seen that the two LTAS are identical. Thus, the background noise did not seem to affect the form of LTAS. It is known that the form of the LTAS is determined by the strongest components of the signal. In this case, due to the short mouth-to-microphone distance (7 cm) the SPL of the teacher’s voice clearly exceeded that of the background noise (in the example the teacher’s voice was 22 dB stronger than the background noise).

4.2.3.3 Perceptual analyses (V)

Two professional voice trainers evaluated perceptually the same two minute voice samples that were used for the LTAS analyses. The samples were randomised on the tape so that the listeners did not know whether a sample was recorded with or without amplification, or whether it was recorded in the first lessons or in the last lesson. However, all the samples of the same subjects were replayed in a row. The listening test was conducted in free field in a damped room using DAT recorder and a Genelec Biamp loudspeaker. The listeners evaluated the voices on a 10 cm Visual Analogues Scale (VAS). The characteristics evaluated are listed in table 8:

Table 8. Characteristics evaluated with VAS scale

<table>
<thead>
<tr>
<th>Overall voice quality</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vocal fatigue</td>
<td>Monopitched, tensed, breathy and hoarse voice (Colton and Casper, 1990).</td>
</tr>
<tr>
<td>Breathiness</td>
<td>Audible escape of air through the glottis due to insufficient glottal closure (Hammarberg, 1992).</td>
</tr>
<tr>
<td>Strainedness</td>
<td>Voice sounds strained as if the vocal folds are compressed during phonation (Hammarberg, 1992).</td>
</tr>
<tr>
<td>Cloudiness</td>
<td>Possibly a perceptual sign of laryngitis or vocal fatigue. Damped, not clear voice. Poor condition of voice.</td>
</tr>
<tr>
<td>Clarity</td>
<td>Opposite to cloudiness: a clear and audible voice. Good condition of the voice.</td>
</tr>
<tr>
<td>Vocal fry</td>
<td>Low-frequency periodic vibration (Hammarberg, 1992).</td>
</tr>
<tr>
<td>Voice breaks</td>
<td>Intermittent frequency breaks (Hammarberg, 1992).</td>
</tr>
<tr>
<td>Throat clearing</td>
<td></td>
</tr>
<tr>
<td>Pitch</td>
<td>The chief auditory correlation of fundamental frequency (Hammarberg, 1992).</td>
</tr>
</tbody>
</table>

Average voice quality was evaluated on a scale from poor (-3) to excellent (+3). Pitch was evaluated either as felt to be appropriate for the speaker and the task, or as too low, or too high.
One of the two listeners evaluated the samples twice in order to calculate intra-observer reliability for the results.

4.3. METHODS FOR STUDY III

4.3.1. Questionnaires for the teachers

The teachers answered two questionnaires at the end of the research period. One questionnaire was for background information, which was discussed in Chapter 4.1.1. The second questionnaire, containing 13 multiple choice questions, registered the teachers' views on the use of amplification in teaching. The questions concerned the effects of amplification on voice production, vocal symptoms, fatigue in the vocal mechanism, general fatigue, progress of the lessons and students' attention. Questions about possible disadvantages arising from the use of amplification were also included. Choices given for each effect were ‘considerable - a fair amount - not much - none’. See Appendix 2.

4.3.2. Questionnaire for the pupils

Students aged 10 years and older (n=664) received a questionnaire on the advantages and disadvantages of using amplification, such as its effects on their capacity to pay attention in a listening situation, on teachers’ diction, and in general whether the students found the amplification annoying or not. Choices given for each effect were ‘very much - much - a little - not’. The students were also asked to describe freely in one to two sentences the advantages and disadvantages arising from the use of amplification. The questionnaires were given out during the last lesson taught with amplification and were filled in immediately; this was done to ensure the best and most accurate response. See Appendix 3.

Students aged 6 – 9 years (n=127) were individually and orally asked 2 questions: Did you like it when your teacher used an amplification system? Why?
4.4. STATISTICAL METHODS

Student’s t-test was used to study the significance of differences between vocal parameters measured (1) with and without amplification and (2) in the first and the last lesson. Spearman correlation was used to study (1) intra- and inter-observer reliability in the listening evaluation and the relation between (2) acoustic and perceptual results and (3) various perceptual parameters.
5. RESULTS

5.1. QUANTITATIVE RESULTS

5.1.1. Effects of amplified and damped feedback on F0, SPL and phonation time
(Studies I, II and IV)

5.1.1.1. In laboratory conditions (I)
Recordings were taken of six females reading aloud while hearing their own voices amplified in headphones. These recordings were analysed. The results suggested that hearing the voice amplified while reading lowered the F0 and SPL significantly. When auditory feedback was damped with earplugs (table 9) the F0 and SPL values were also significantly lowered compared to recordings without amplification.

Table 9. Mean fundamental frequency (F0) and sound pressure level (SPL) of six females for reading with and without amplification and damping and the statistical significance of the difference (paired samples t – test).

<table>
<thead>
<tr>
<th></th>
<th>F0 (Hz)</th>
<th>SPL (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>with</td>
<td>without</td>
</tr>
<tr>
<td>Amplification (n=72)</td>
<td>171</td>
<td>174</td>
</tr>
<tr>
<td>Damping (n=72)</td>
<td>180</td>
<td>182</td>
</tr>
</tbody>
</table>

During amplified auditory feedback the changes in F0 and SPL correlated positively with each other (r 0.64, p<0.001). Maximum decrease in F0 was 1 semitone and that in SPL was 6 dB compared to recordings without amplification. During damped feedback there was a weak negative correlation between F0 and SPL changes (r-0.27, p=0.020). The maximum decrease in F0 was 2 semitones and that of SPL was 4 dB compared to recordings without amplification.

5.1.1.2. Amplification in classrooms (II, IV)

5.1.1.2.1. F0 and SPL
Results from 4 minutes samples (taken from the very beginning, middle and end of a lesson. Both the first and the last lessons were included) showed that amplification lowered significantly F0 and SPL both for females and males (table 10).
Table 10: Mean values of fundamental frequency (F0) and sound pressure level (SPL) in teachers’ classroom speech with and without amplification and the statistical significance of the difference (paired samples t-test).

<table>
<thead>
<tr>
<th></th>
<th>F0 (Hz)</th>
<th></th>
<th>SPL (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>with</td>
<td>without</td>
<td>sig.</td>
</tr>
<tr>
<td>females (n=3)</td>
<td>276</td>
<td>284</td>
<td>p=0.002</td>
</tr>
<tr>
<td>males (n=2)</td>
<td>135</td>
<td>146</td>
<td>p&lt;0.000</td>
</tr>
</tbody>
</table>

5.1.1.2.2. F0 time (II)
Amplification seemed to decrease and increase the phonation time for the genders in the 4 minute samples, but the changes were statistically non-significant (table 11).

Table 11: Mean values of phonation time (F0 time in percentages of 4 minutes total sample duration) in teachers’ classroom speech with and without amplification: the difference caused by amplification was statistically non-significant at 5% level (paired samples t-test).

<table>
<thead>
<tr>
<th></th>
<th>with</th>
<th>without</th>
</tr>
</thead>
<tbody>
<tr>
<td>females (n=3)</td>
<td>88.5%</td>
<td>82.8%</td>
</tr>
<tr>
<td>males (n=2)</td>
<td>70.9%</td>
<td>84.0%</td>
</tr>
</tbody>
</table>

5.1.2. Effects of amplified and damped auditory feedback on Long-term-average-spectrum (I, V)

5.1.2.1. In laboratory conditions (I)
Level difference between the region of F1 and the region of F0 (F1-F0) decreased significantly with amplification, suggesting a relatively stronger fundamental. The spectral slope became steeper (weaker overtones) as shown by a decrease in alpha ratio (by dividing the SPL of the range 1 – 10 kHz by the SPL of the range 50 Hz – 1 kHz) when the subjects heard their voices amplified through headphones (p<0.001) (table 12).
Table 12: Mean Long-term-average-spectrum (LTAS) characteristics for normal reading without wearing headphones and while hearing own voice amplified through the headphones (left) and normal reading before wearing earplugs and for reading while wearing earplugs (right) and the statistical significance of the difference at 5% level (paired samples t-test). NS = non-significant.

<table>
<thead>
<tr>
<th></th>
<th>normal (n=72)</th>
<th>amplified (n=72)</th>
<th>sig. normal (n=72)</th>
<th>earplugs (n=72)</th>
<th>sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1-F0</td>
<td>12.7</td>
<td>11.7</td>
<td>p&lt;0.001</td>
<td>13.3</td>
<td>13.3</td>
</tr>
<tr>
<td>F1 (2-5 kHz)</td>
<td>19.0</td>
<td>18.9</td>
<td>NS</td>
<td>18.7</td>
<td>18.6</td>
</tr>
<tr>
<td>F1 (5-10 kHz)</td>
<td>29.3</td>
<td>28.7</td>
<td>p=0.005</td>
<td>29.4</td>
<td>29.4</td>
</tr>
<tr>
<td>Alpha ratio</td>
<td>0.85</td>
<td>0.83</td>
<td>p=0.001</td>
<td>0.85</td>
<td>0.86</td>
</tr>
</tbody>
</table>

5.1.2.2. Amplification in classrooms (V)

In general the slope of the LTAS was steeper when amplification was used. The difference between ordinary condition and amplification was prominent in the first lesson (table 13).

Table 13: Mean Long-term-average-spectrum (LTAS) values for the first and last lesson without and with amplification and the statistical significant of the difference at 5% level (paired samples t-test) NS = non-significant.

| kHz   | First lesson | Last lesson | | | |
|-------|--------------|-------------|--------------|------------|
|       | with amplification | without amplification | sig. | with amplification | without amplification | sig. |
| 1-2   | -13.6        | -10.1       | p=0.004      | -11.2      | -10.9       | NS   |
| 2-3   | -22.6        | -20.9       | NS           | -20.5      | -20.4       | NS   |
| 3-4   | -27.2        | -24.1       | p=0.005      | -25.5      | -24.1       | NS   |
| 4-5   | -33.4        | -29.8       | p=0.022      | -29.9      | -29.6       | NS   |
| 5-10  | -40.8        | -35.9       | p<0.001      | -40.8      | -34.5       | p=0.040 |

5.1.3. Working-day-related changes (IV, V)

5.1.3.1. Changes in F0 and SPL (IV)

There was an increase in F0 and SPL during the teachers’ working-day whether amplification was used or not. This increase was larger and statistically significant when amplification was used (table 14). For each subject there was a general trend that F0 was higher during the last lesson but there were also relatively large changes in F0 during the lesson. A positive correlation between F0 and SPL was found in both conditions (r 0.50, p=0.027 in normal conditions; r 0.50, p=0.005 with amplification) (table 14).
Table 14: Mean value of fundamental frequency (F0) and sound pressure level (SPL) in first and last lesson without and with amplification and the difference with statistical significance at 5% level (paired samples t-test). NS= non-significant.

<table>
<thead>
<tr>
<th></th>
<th>Without amplification (n=5)</th>
<th>With amplification (n=5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First lesson</td>
<td>Last lesson</td>
</tr>
<tr>
<td>F0</td>
<td>227</td>
<td>231</td>
</tr>
<tr>
<td>SPL</td>
<td>75.4</td>
<td>76</td>
</tr>
</tbody>
</table>

5.1.4. Changes in spectrum (V)

The spectral slope became seemingly less steep in the course of the teachers’ working day when amplification was used but the difference between the two conditions was non-significant (fig. 6, 7). Without amplification, a similar trend could be seen at 5 – 10 kHz (fig. 6). No significant changes were observed in spectral tilt between first and last lesson in ordinary conditions (fig. 6). During amplification the slope decreased significantly (p=0.045) at the ranges of 1-2 kHz, (p=0.038) at the ranges of 2–3 kHz, (p=0.012) at the ranges of 4-5 kHz and (p=0.020) at the ranges of 5–10 kHz (fig. 7).

Figure 6. Average Long-term-average-spectrum (LTAS) values in 5 subjects in first and last lesson without amplification
5.1.4.1. Gender related changes in Long-term-average-spectrum (V)

In ordinary conditions no significant differences were seen in the results for LTAS between the genders. During amplification the two males showed somewhat different results from the females; the spectral tilt in the male voices decreased less or increased at some ranges during the working day.

Table 15. Mean differences in Long-term-average-spectrum (LTAS) characteristics between the first and last lesson (last lesson value minus first lesson value) with and without amplification for females (n=3) and males (n=2). Mean level differences between the strongest component in the LTAS and the strongest components between 1-2 kHz, 2-3 kHz, 3-4 kHz, 4-5 kHz and 5-10 kHz. Significance of the difference between females and males (paired Student’s t-test) is given at 5% level of significance. NS = non-significant (p > 0.050).

<table>
<thead>
<tr>
<th></th>
<th>1-2 kHz</th>
<th>2-3 kHz</th>
<th>3-4 kHz</th>
<th>4-5 kHz</th>
<th>5-10 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>With Amplification</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females</td>
<td>3.9</td>
<td>4.1</td>
<td>3.5</td>
<td>5.7</td>
<td>6.5</td>
</tr>
<tr>
<td>Males</td>
<td>-2.1</td>
<td>1.2</td>
<td>-0.5</td>
<td>1.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Sig.</td>
<td>0.033</td>
<td>0.032</td>
<td>0.034</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Without Amplification</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females</td>
<td>0.1</td>
<td>-0.1</td>
<td>0.4</td>
<td>-0.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Males</td>
<td>0.04</td>
<td>-0.9</td>
<td>-1.2</td>
<td>0.03</td>
<td>-1.0</td>
</tr>
<tr>
<td>Sig.</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>
5.2. QUALITATIVE RESULTS (III, V)

5.2.1. Teachers’ opinions on amplification in classroom (III)

5.2.1.1. Advantages

The large majority, some 91% of the 33 teachers, agreed that the use of an amplification system was beneficial both for voice and for communication in class. Amplification made voice production easier (97%), decreased vocal symptoms and fatigue in vocal mechanism (88%), decreased fatigue in the body (61%) and reduced the need for repetitions (82% of the teachers stated they needed to repeat themselves when not using amplification, in comparison with 9% when using amplification). Additionally, teachers agreed that students' performance was better because concentration was improved.

5.2.1.2. Disadvantages

The teachers described briefly what they found disadvantageous while using amplification. One third of the teachers reported that they lacked sufficient skills in installing and using the amplification system correctly, one fifth of the group declared they found it inconvenient (e.g., it was difficult to transport the equipment between classrooms) and one fifth felt that there were no, or few, disadvantages. One fourth did not reply.

5.2.2. Students'/pupils’ opinions on amplification in classroom (III)

5.2.2.1. Advantages

Of the 664 students who were given a questionnaire 528 returned answers (316 girls and 212 boys). The most commonly cited advantages (77-87% of all respondents) were listening was easier, it was easier to hear through class chatter, and easier to follow the lessons (fig. 8).

About half of the group (between 45% and 63%) noted that there was less class chatter, fewer repetitions by the teacher, and that it was easier to concentrate on the lessons. Sixty six percent of the students declared that they would remind their teacher to use the amplification if he or she forgot to turn it on.
Of the students’ free comments on the teacher’s use of amplification, most (87%) statements were to the effect that they could hear better (fig. 8). Among the youngest pupils (6-9 years of age) the percentage was more than 95%.

5.2.2.2. Disadvantages

One third of the learners’ group found excessively loud sound from the system and one fifth of the group found the amplification annoying. Of the students’ free comments concerning disadvantages, most concerned technical problems or lack of technical skill of the teachers.

5.2.3. Perceptual evaluation of the teachers’ voices (V)

5.2.3.1. Voice quality with and without amplification in classroom

Voices were perceived as significantly better in quality (p=0.004), less strained (p=0.029), less rough (p=0.027), less asthenic (p=0.043) and with fewer voice breaks (p=0.030) when amplification was used. On the other hand, there were no significant perceptual differences in pitch, breathiness, clarity, vocal fry, clearing and fatigue between the two conditions. Intra-observer consistency was satisfactory for all characteristics (r>0.50, p<0.001) except for vocal fry and vocal fatigue. For roughness intra-observer consistency was found low (r 0.42, p=0.012). Intra-observer consistency was satisfactory for pitch, vocal fry and clearing, whereas there was very little consistency for roughness, asthenity, breathiness, clarity and vocal quality.
5.2.4. Perceptual evaluation of the teachers’ voices (V)

5.2.4.1. Voice quality with and without amplification in classroom

Voices were perceived significantly better in quality (p=0.004), less strained (p=0.029), less rough (p=0.027), less asthenic (p=0.043) and with fewer voice breaks (p=0.030) when amplification was used. On the other hand, there were no significant perceptual differences in pitch, breathiness, clarity, vocal fry, clearing and fatigue between the two conditions. Intrarater reliability was satisfactory for all characteristics (r>0.50, p<0.001) except for vocal fry and vocal fatigue. For roughness intrarater reliability was found low (r 0.42, p=0.012). Interrater reliability was satisfactory for pitch, vocal fry and clearing, whereas roughness, asthenity, breathiness, clarity and vocal quality got low scores.

5.2.4.2. Changes in voice quality during working-day

No significant difference was found in changes in perceived voice quality during a teacher’s working day except a small tendency for less asthenity while amplification was used (p=0.100).

5.2.4.3. Correlation between perceived voice quality and acoustic analyses.

Table 16 shows that voice quality correlated negatively with spectral slope, indicating that voices with steeper slope (weaker overtones) were perceived better. That is most likely due to the fact that strainedness correlated positively with spectrum slope.

Table 16: Spearman correlations, statistically significant at 5% level, between perceived voice quality and results of acoustic analyses. n=5.

<table>
<thead>
<tr>
<th></th>
<th>1-2 kHz</th>
<th>2-3 kHz</th>
<th>3-4 kHz</th>
<th>4-5 kHz</th>
<th>5-10 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>r</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significance</td>
<td>p</td>
<td>0.001</td>
<td>0.007</td>
<td>0.000</td>
<td>0.002</td>
</tr>
<tr>
<td>Strainedness</td>
<td>r</td>
<td>0.49</td>
<td>0.47</td>
<td>0.32</td>
<td>0.59</td>
</tr>
<tr>
<td>Significance</td>
<td>p</td>
<td>0.000</td>
<td>0.000</td>
<td>0.013</td>
<td>0.000</td>
</tr>
<tr>
<td>Breathiness</td>
<td>r</td>
<td>-0.29</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Significance</td>
<td>p</td>
<td>0.032</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Vocal fry</td>
<td>r</td>
<td>-0.41</td>
<td>-</td>
<td>-0.14</td>
<td>-0.55</td>
</tr>
<tr>
<td>Significance</td>
<td>pr</td>
<td>0.002</td>
<td>NS</td>
<td>NS (0.071)</td>
<td>0.000</td>
</tr>
</tbody>
</table>
6. DISCUSSION

It is well documented that outside factors such as poor acoustics, background noise and too great a distance between the teacher and the students affect both the voice of the teacher and the student's capacity to hear properly what is being said (Markides, 1986; Pekkarinen and Viljanen, 1990; Vilkman, 1996; Crandell and Bess, 1986; Pekkarinen, 1988).

The aim of this study was to discover whether amplification in the classroom might benefit teachers and students and, if so, what form these benefits might take. As the teachers participated voluntarily in the research, an interesting question was posed. Why did they wish to try amplification? Was it perhaps because of poor vocal health? If so, the results may not be typical for teachers in general. However, the background information from the 33 subjects in this research indicated that they were not suffering more acutely from vocal symptoms than their colleagues in other countries have in general reported (e.g., Sapir, 1993). This sample thus seems to be representative of the teaching profession. Additionally, according to questionnaire results from this study, reported symptoms seem to have been due to work-induced vocal load since no subject complained of any vocal symptoms during the summer vacation. These results bear out the results of Sala et al. (2001), who found during research into vocal symptoms of teachers in a day care centre that most complaints were reported during working hours, while no complaints of any vocal symptoms were reported during vacations.

Apart from their readiness to volunteer, the group of teachers had little in common: their ages, gender, teaching experience, their teaching methods and teaching environments, the size of the classrooms and the numbers and ages of students in class were all different. The purpose of this study was to obtain a varied selection of subjects so that although the number of the subjects was limited, they formed a representative group. It can also be regarded as advantageous that teachers showing voice symptoms were included in the sample, since it is precisely these teachers who would appear to have most to gain from amplification.

In Studies II, IV and V both female and male voices were quantitatively examined. F0 and SPL were examined in Studies II and IV, and spectrum characteristics in Study V. In some earlier field studies on teachers’ vocal behaviour the female voice has been the principal focus (Rantala et al., 1994; Ohlson, 1988; Pekkarinen et al., 1992). As far as we know no studies have been made on male voices under working conditions in classrooms. Comparable research results on voice parameters in males must therefore be sought amongst males who were not teachers (Novak et al., 1991; Lauri et al., 1997).
6.1. CHANGES IN FUNDAMENTAL FREQUENCY, SOUND PRESSURE LEVEL AND SPECTRUM

6.1.1. Changes during amplified and damped auditory feedback in laboratory conditions (I)

6.1.1.1. Fundamental frequency and sound pressure level

Amplified auditory feedback lowered significantly F0 and SPL. This is much in line with earlier studies where amplified feedback has been studied in laboratory and field conditions (Laukkanen, 1990; Sapienza, 1999).

It is well known that speakers tend to increase the loudness of speech with the ambient noise level – this is the so-called Lombard effect (Van Heusden, 1979). Laukkanen (1990) reported increased voice loudness when subjects’ voices were masked by headphones while reading aloud. It was therefore considered to be of interest to test the effects of damped auditory feedback. Indeed, inverse results to the Lombard effect were found during damped auditory feedback: F0 and SPL decreased.

Lower F0 during amplification can be a by-product of a lower SPL (Sundberg, 1987; Titze, 1992). Compared to the effects of amplified auditory feedback F0 decreased relatively more than SPL in damped auditory feedback. Furthermore there was a negative correlation between the changes in F0 and those of SPL. Therefore F0 changes during damped feedback seem not to be a co-product of changes in SPL. It is tenable to assume that the causes are of both acoustical and physiological origin for the following reasons:

a) the dampening effect caused by the ear plugs was weaker at lower frequencies (below 500 Hz), so lower frequencies became more prominent;
b) the role of bone conduction increases during damping, causing higher pitched components to become weaker;
c) Since the higher components of the signal become weaker the sound is heard to be darker. Laukkanen (1994) demonstrated how people may adapt to the lower pitch they hear - especially if they like a lower pitched voice. Additionally, according to Lieberman (1967) people seem to have an inborn behavioural pattern of adapting their pitch according to the speaking pitch levels they hear in their environment.

6.1.1.2. Spectrum

During amplification statistically significant decreases were found both in F1-F0 level difference and in alpha ratio. However, when auditory feedback was damped no significant difference was found in any spectrum components. Decreased F1-F0 level difference suggests a relatively stronger fundamental. The relative strength of the fundamental in the source spectrum has been found to correlate positively with the glottal opening width (Gauffin and Sundberg, 1980). In turn alpha ratio measurements illustrate
the average spectral slope. Gauffin and Sundberg (1980) pointed out that source spectrum slope correlated positively with the closing speed of the glottis. A pressed voice production with a strong vocal fold adduction is characterized by a relatively weak fundamental and decreased spectral slope and a strained, hyperfunctional voice. Production with a weak adduction is characterized by a relatively strong fundamental but increased spectral slope (Gauffin and Sundberg, 1980, 1989). Voice production with decreased F1-F0 level difference and alpha ratio may therefore suggest a turn towards a more hypofunctional direction during amplified auditory feedback. This is natural as SPL was lower with amplification, too.

6.1.2. Changes during amplification in class (II, IV,V)

To record a teacher's speech in working conditions may give a more reliable picture of the voice as it undergoes variations in vocal characteristics caused by physiological, emotional, educational and disciplinary factors during the day. In this study, the values obtained in the laboratory are within the limits of mean F0 reported in research literature (see Krook, 1988, for further review). However, the F0 values obtained in the field exceed those limits. This corresponds with the Rantala et al's (1998) laboratory and field studies, where the same discrepancy appeared. In field studies, because of the Lombard effect, talking to an audience against background noise and in a large room inevitably results in a rise in SPL and a consequent rise in F0 (or people raise F0 in order to raise SPL; for a review, see Vintturi, 2001, p.44-45).

6.1.2.1. Changes in fundamental frequency and sound pressure level

Results both from laboratory and field conditions have shown that amplified auditory feedback lowers SPL (Laukkanen, 1990; Sapienza, 1999; Chang – Yit et al., 1975). In this instance also, amplification significantly lowered both F0 and SPL in teachers’ classroom speech. This was the case for all the five subjects in the present study. For females this lowering was about 10 Hz and 1 dB, for males about 11 Hz and 1 dB. The fact that Sapienza et al. (1999), in their study on 15-minutes lectures given by 10 teachers (6 males and 4 females) in an unoccupied classroom, found an average decrease of 2.4 dB during amplification could be due to differences in the level of amplification used in these studies. As no voice samples of the subjects’ conversational voice were included in this study it is impossible to say if or how much rise there was in F0 and SPL in the classroom speech as compared to habitual speech.

Many findings, from both laboratory and field conditions, have shown a rise in F0 and/or SPL after vocal loading (e.g., Gelfer et al., 1991; Ohlson, 1988; Rantala et al., 1998; Novak et al., 1991, Pekkarinen et al., 1992; Stemple, 1995). Without amplification there were no significant differences in F0 and SPL between the first and the last lessons. This may indicate that vocal loading had caused a rise in F0 and SPL during the first lesson taught and that this state had continued throughout the entire working day, possibly because the first lesson had been so demanding that the teacher no longer had any resources for a normal, physiological increase of F0 and SPL. In contrast when using
amplification, F0 and SPL were significantly higher in the last lessons. The reason may be due to causes listed below, factors which, generally speaking, can all be cited as explanations of why F0 and SPL rise during the working day, and are, therefore, postulated mechanisms in general.

a) Adaptation to vocal loading: Rantala and Vilkman (1999) found a greater increase during a working day in these parameters for those female teachers who had fewest voice complaints. It has therefore been hypothesized that a sufficient vocal loading-related rise in F0 and SPL shows the vocal organ’s ability to adapt adequately to vocal loading (Rantala and Vilkman, 1999). According to background information the subjects of the present study experienced fewer vocal symptoms when amplification was used. This favours the hypothesis that a vocal loading-related increase in F0 and SPL is not, as such, a sign of vocal fatigue. This is also in line with Vintturi et al’s (2001) results on the effects of vocal warm-up (WU), where WU shifted the voice production in a hyperfunctional direction.

b) Tissue viscosity: The vocal fold vibration is set in motion according to the mobility and deformability of vocal fold mucosa, and the degree of irrigation by body fluids of this mucosa plays a key role in how easily this vibration is achieved (Titze, 1994). If the vocal fold mucosa dried during the working-day, it could lead to a need to produce voice with greater effort (due to stiffer mucosa) and, thus, increased F0 and SPL. (Verdolini – Marston et al., 1990; Sihvo, 1997). Scherer et al. (1987), found that abusive voice production leads to swollen vocal folds anteriorly with edema of both vocal folds and perturbation in jitter and shimmer. However if the mucosa swelled (i.e., contained more water), it could possibly lead to decreased viscosity (i.e., closer to the lesser viscosity of water). Thus, the effect of vocal fold oedema would possibly not be an increase in effort; moreover, a swollen vocal fold vibrates with lower F0.

c) Circadian rhythm: In their investigation on F0 and SPL in female and male teachers’ voices Artkoski et al. (2002) showed that there seems to be a tendency for F0 to rise in the afternoon even when the voice has not been used. This may be due to changes in psycho-physiological activity related to the circadian rhythm of the human body (Bouhys et al., 1990).

d) Emotional causes: As F0, SPL and glottal waveform reflect the speaker’s mood (Laukkanen et al., 1996), changes in voice may be expected in prolonged voice use not least in the voices of teachers, who have to use their voices both as educational and disciplinary tools.

Changes in F0 and SPL can be seen amongst individual subjects in samples taken from the very beginning, middle and the ending of the lessons (IV). What was characteristic of the use of amplification was a tendency for there to be a rise in F0 in the end of the last lessons in the working day (IV). Effects of situational factors (type of classroom communication, emotional and other psycho-physiological states of the teacher, etc.) cannot be excluded. It is therefore possible that as the day wore on students may have become less attentive, especially at the end of the school day. This may have lead to increased use of the voice as a disciplinary tool by the teacher, or teachers may have become used to the amplification and tended to return to their former vocal habits when class communication worsened. However, on the basis of listening analysis on the
content of the classroom speech there did not seem to be much difference between the last lessons with/without amplification in this respect.

When not using amplification these tendencies towards higher F0 at the end of the last lesson were not as characteristic as when amplification was used. Indeed, with three of the subjects the opposite happened: the F0 became lower at the end of the last lesson. This fall in F0 could be interpreted as a sign of vocal fatigue after prolonged voice use in classroom noise.

6.1.2.2. Phonation time

Amplification did not significantly change phonation time. This confirms the questionnaire answers (III) where only 4% of the 33 teachers stated that they talked more using amplification. On the other hand, the verbal style of the teachers could have differed when using amplification. With perceptual analysis it was noticeable that teachers spent more time in the exposition of their teaching material when amplification was used and less time repeating themselves and/or establishing discipline, which was frequently done when not using amplification.

6.1.2.3. Spectrum

With amplification for both first and last lessons there was an increase in spectral slope for all measured ranges (1-2 kHz, 2-3 kHz, 3-4 kHz 4-5 kHz and 5-10 kHz) compared to unamplified conditions. The differences between amplified and unamplified lessons were considerably greater for the first lesson than for the last lesson. For the first lesson amplification increased the slope on the average 3.5 dB for 1-2 kHz and 1.7 dB for 2-3 kHz. For the last lesson this difference was on the average only 0.3 dB for 1-2 kHz and 0.1 dB for 2-3 kHz. This suggests that in the first lesson with amplification the subjects used softer voices with lower vocal effort, i.e. decreased force in the closing of the vocal folds, diminished respiratory activity and less speed in the glottal closing. This is known to induce less fatigue. While using amplification there was however a significant rise in spectrum in the last lessons. It may be hypothesized that increased activity in the laryngeal muscles and/or decreased viscosity in the vocal fold tissue had taken place. A change towards a less steep spectral slope can be seen as one of the normal vocal-loading related changes in the voice. Rantala and Vilkman (1999) found that energy changes in higher spectral components increased during a working day for teachers with fewer vocal complaints. However, those changes, typical of adaptation, may also be seen as reflecting hyperfunction, i.e. too strong adduction and subglottal pressure leading to fatigue changes.

When the subjects were not using amplification few changes were seen in the spectrum during the working day. As the subjects reported they suffered from multiple vocal symptoms, the results are in line with Rantala et al’s study (1998) which found negligible changes in spectrum over a working day for teachers with many vocal symptoms. Small changes in the spectrum in classroom speech under ordinary conditions could indicate that the subjects already started to use strained loud voices in the first lessons. It is well
known that higher spectral harmonics gain more in amplitude than the lower harmonics when SPL is raised (e.g., Sundberg, 1987; Löfqvist, 1986; Gramming, 1991). Additionally, as the spectrum slope is positively related to the speed of the glottal closing, it may be said that a less steep slope is demonstrating stronger overtones. High speed in the closure means harder collision, which may be harmful to the vocal folds (Scherer et al., 1987).

6.1.2.4. Work-related changes in spectrum according to gender

Study results have shown that female voices tend to change in a hyperfunctional direction during vocal loading (Novak et al., 1991; Rantala et al., 1998; Löfqvist, 1986; Ohlson, 1988; Lauri et al., 1997). In contrast, the spectra of male voices have shown fewer changes during vocal loading (Lauri et al., 1997) or even an opposite tendency, becoming hypofucntional during vocal loading (Novak et al., 1991).

In Studies II, III, IV and V there were 3 female voices and 2 male voices. The spectra of the female voices in the last lesson without amplification were well in line with earlier studies, which showed a less steep spectrum after vocal loading (Rantala et al., 1998; Novak et al., 1991). Additionally, these changes in spectrum for female voices during vocal loading are in keeping with studies on a) changes in time-based glottal flow waveform parameters (Lauri et al., 1997) showing increased SQ (speed quotient) and decreased CIQ (closing quotient), b) studies on amplitude domain changes showing increased d_{peak}, increased f_{AC} (Vilkman et al., 1999), c) increased F0, increased subglottal pressure and increased SPL after vocal loading (Kitzing, 1979; Gelfer et al., 1991; Vilkman et al., 1999; Rantala and Vilkman, 1999). In fact these same changes (increased F0, increased subglottal pressure and increased SPL) were present in males in Vilkman et al’s study (2002). All above mentioned parameter changes reflect a shift towards more effortful or hyperfunctional voice production.

In the present study, one of the males in his last lesson of the day without amplification equipment showed a tendency to become hypophonic, marked by a steeper slope in the spectrum. In this subject, during the last lesson, a still greater increase was seen in the slope while using amplification. This teacher had been teaching for 8 hours this day, according to schedule, with short breaks. In the last lesson taught without amplification he was clearing his throat, hesitating and repeating himself – the implication being that he was becoming fatigued. This was not the case when he was using amplification in the last lesson, which could point to less fatigue due to use of the amplifier.

In the case of the other, older male who reported suffering from more severe voice problems, the spectrum showed the same trend as the female voices, i.e. it became more hyperfunctional during vocal loading. This raises the question as to whether the different results obtained for males and females in vocal loading tests are due to gender or to individual differences in vocal endurance. There is individual variation in all vocal characteristics so what may be related to vocal fatigue in one subject may not be related to it in another. Thus, hypofunctional voice may be a sign of fatigue - a kind of a “giving
up” reaction. Alternatively, hyperfunctional quality may be due to an attempt to overcome changes related to fatigue or be simply a sign of successful adaptation to loading.

From a physiological point of view the female voice may be more vulnerable to vocal loading due to physiological causes, such as smaller and weaker structure of the vocal mechanism (Bridger and Epstein, 1983; Fritzell, 1996; Herrington-Hall et al., 1988; Lauri et al., 1997; Vilkman, 2000). The fact that female vocal folds vibrate roughly twice as often per unit time (Vilkman, 2000) as those of male may be a crucial factor in this respect. According to Lauri et al. (1997), females tend to increase glottal adductory force as a response to vocal loading. Jiang and Titze (1994) pointed out that impact stress (the force with which the vocal folds collide) increases as a function of F0 and SPL and adduction. However, the results of this preliminary study should be taken with caution as the number of the subjects limits the possibilities of drawing conclusions. Whatever may be the case, the results call for further investigation into possible differences in vocal behaviour according to gender. It is tenable to hypothesize that female vocal folds may behave differently in loading tests because of the differences in laryngeal structure.

6.2. LISTENING EVALUATION (V)

Results of the listening evaluation of the voice samples by the author suggest that when teachers used amplification, they went into greater detail, repeated themselves less, and used less of their time in establishing discipline.

According to the voice trainers’ listening evaluation, voice quality was not found to be good in any of the samples, either in those taken under amplification or those in non-amplified conditions. All the teachers had long teaching experience and according to the results of research questionnaires their profession is considered to be at high risk for voice problems, so the results from listening evaluation should not be a surprise. However, the voices were perceived as less strained in amplified conditions, which is in accordance with the lower F0, SPL and steeper spectral slope. This indicates softer adduction. Additionally, the perceived strainedness increased during the working day somewhat more when amplification was used, possibly due to a "lower baseline level", i.e. less strainedness in the first lesson due to amplification. This was also in accordance with the acoustical measurements that showed a greater decrease in spectral tilt compared to unamplified conditions. As strainedness correlated positively with a decreased spectral tilt so did asthenity and breathiness correlate with increased spectral tilt. This is in line with earlier findings (Hammarberg, 1986; Kitzing, 1986). As the present material consisted of relatively loud classroom speech it was not expected to find vocal fry which exists in quite low-pitched and relatively soft speech. Roughness, though to a relatively limited extent, was found more often in voice samples taken in non-amplified conditions. Roughness is related to irregular vocal fold vibration, and that in turn has been found to increase when there is hyperfunctionality in the voice (Beckett, 1969), or when the vocal fold condition is not good - e.g., due to vocal fatigue. The fact that the voice was found to be less asthenic in amplified conditions may be related to lower F0 and therefore a lower
load. Additionally the voice was perceived as more relaxed when using amplification, which may have given the voice a more natural timbre.

The spectral slope decreased clearly during the day with amplification as stated above. However, for the listeners the voices sounded only slightly less asthenic in the samples from the last lessons. This discrepancy between clear change in LTAS and less clear change in perception may be due to the fact that the strongest parts of the signal mark the form of the LTAS but these strongest parts may not necessarily be those most apparent to the listener.

The measured mean difference in average F0 without and with amplification was 0.66 semitones expressed on a musical scale. That may be the reason why no differences were found in perceived pitch although there were differences in F0. A difference that is less than 1 semitone may be too slight to be perceived by any but those with perfect pitch. Additionally, as the samples were in random order it was difficult if not impossible to detect pitch differences. Perceptual differences in average speaking pitch cannot be expected to be as accurate as acoustically measured average F0, especially in a speech sample in which pitch varies all the time.

Vocal fatigue is a difficult quality to deal with because it is identified by subjective interpretations of varied characteristics of the voice. This may be the explanation why no significant difference was found in perceived vocal fatigue in samples recorded in the two conditions (with and without amplification), and why inter-observer consistency (between listening evaluations by two listeners) was low for perceived vocal fatigue. The cloudiness and roughness correlated, however, with the perception of fatigue for both listeners, which is in line with earlier study results where those vocal characteristics have been found to coincide with perceived fatigue (Laukkalan et al., 2001). As these voice samples were from loud classroom speech which varied in pitch it is plausible to assume that some characteristics were unlikely to exist in the samples, e.g., vocal fry, where there was low intra-observer consistency found. Likewise low inter-observer consistency was found in asthenity, breathiness and roughness.
6.3. TEACHERS’ AND STUDENTS’ OPINIONS ON AMPLIFICATION IN TEACHING (III)

6.3.1. The teachers

Only two of the 33 teachers in Study III were familiar with the use of amplification before the test. It is therefore possible that general satisfaction with the use of amplification could stem from the effect that attention was paid to the amplified feedback and, therefore, more attention focussed on the teachers’ own voice use. The result may have been that the teachers used softer voices with amplification, resulting in softer adduction of the vocal folds. Indeed that is in accordance with lowered F0, SPL and increased spectral tilt.

While using amplification the teachers reported less fatigue in the vocal mechanism, especially in the throat, which may be partly related to decreased levels of F0 and SPL. Additionally, the majority of the subjects reported better voice production and less fatigue in the body. It is possible to conclude that stress had become less, especially when it is remembered that the teachers found that students paid more attention, there was less classroom chatter, and they felt less need for repetition. Interestingly, all of the subjects admitted to discomfort in the voice mechanism when teaching without amplification. While using amplification, only 14 (42%) of the subjects answered this question which may suggest that no discomfort was felt.

The results suggest also that vocal load at work has a significant effect on the general well-being of the voice professional.

6.3.2. The students

Leavitt and Flexer (1991) used Rapid Speech Transmission Index (RASTI) to estimate speech perception in a classroom. According to their results only 55% of the sound energy is available to the listeners in the centre of the back row of seats in a classroom. When Crandell and Bess (1986) examined the speech recognition of young children (5 to 7 years old) they found that there was a systematic decrease in speech-recognition ability as speaker-listener distance increased. Those experiments were carried out in what they called “typical” classroom environment (signal to noise ratio = +6dB; RT =0.45 s.).

It is to be regretted that it was not possible to carry out acoustical measurements of the classrooms in this present study because no acoustic devices were available in Akureyri. In the present study we therefore do not know the acoustical conditions in the classrooms. The size of the classrooms varied considerably (from 40m² in a junior college classroom up to a 158 m² auditorium in the university and a gymnastic hall of 175 m²). The distance
between the teacher and the pupils therefore varied considerably. In their free comments on the teacher's use of amplification, three quarters of the students commented that they heard better. This was also the case for over 95% of the youngest students (6-9 years old). In addition, the students stated that the use of an amplification system facilitated listening and improved concentration. Surprisingly few students found the amplification annoying in spite of simple and inexpensive equipment. It may be because: a) this generation is so used to amplified sound that it is not so sensitive to its flaws and disadvantages, or b) hearing problems among young people are increasing (Ray Hull, personal contact 2001). Listening abilities could therefore be poorer than one would expect. For some students the pleasure of being able to hear better may cause them to overlook discomfort. A comparison with other studies concerning this aspect of the research is difficult, as general use of amplification for non-handicapped children in classrooms is still not common practice. Research on the effects of amplification on behaviour or learning difficulties in children has shown positive results and, additionally, positive effects on the voice of the teacher (Palmer, 1998; Allen and Patton, 1990; Gilman and Danzer, 1989).

As far as vocal health is concerned, the benefits reported by teachers and pupils in this study are much in line with results from other studies – 1) for teachers: reduced voice fatigue, less need for repetition, improved student attention, improved behaviour, fewer distractions, diminished discipline problems 2) for students: easier to hear the teacher, improved attention, class noise diminished, teacher heard without the need for straining (Sarff, 1981; Berg et al., 1989; Gilman and Danzer, 1989; Allen and Patton, 1990; Rosenberg, et al., 1994; Palmer, 1998; Flexer, Millin and Brown, 1990; Lehman and Gratiot, 1983).

6.3.3. Problems related to amplification

Teachers and students agreed that the main disadvantages related to amplification stemmed from technical problems and the teachers' lack of knowledge about the proper use of the equipment; they cited too much amplification, acoustic feedback and problems experienced in setting up the equipment. This is very much in line with what Flexer et al. (1995) indicated might be the main disadvantages with amplification in classrooms, when they cited too much amplification, inappropriate amplification systems in the classroom and insufficient technical knowledge in the teacher. Flexer et al. (1995) emphasised a) the necessity for teachers to learn how to use the equipment; b) an appropriate amplification system for the room; c) appropriate number and positioning of loudspeakers; d) user-friendly microphones placed at the correct distance from the mouth of the speaker (6 inches is recommended) and e) someone with adequate expertise available in the school district to install and maintain the equipment. In Icelandic schools where amplification is available, experience has shown that the amplification system has to be simple to use and there is a need for a suitable expert within the school itself. If the teachers are not taught to use the equipment, or if some problem arises with which they cannot cope, they stop using it. As communication between teacher and student begins as soon as the teacher enters the classroom and teachers cannot waste time tuning a complicated system, it is important that the equipment is as simple to use as possible.
As amplification in ordinary classrooms has been rare up to now, it is possible that some technical problems may arise with more widespread use. Boothroyd (1992) pointed out that if too few bands are made available there may be a limit on the number of sound field units which can be installed in the same building, while too many bands per carrier frequency may increase interference and unfavourable S/N ratio within the equipment itself.

6.3.4. Improving the teachers’ vocal ergonomics

It is plausible to assume that the main cause of the voice problems which are known to afflict teachers may be rooted in general lack of knowledge about voice production and the capacity of the voice. This widespread ignorance has meant that not enough attention has been given to “vocoergonomic” considerations, such as a) training teachers in the care of the voice and b) ensuring that classrooms are acoustically adequate for their purpose, e.g., by limiting reverberation time and equipping larger rooms with amplification equipment. Up to the present, there has been a gross lack of understanding of the issues by those concerned, amongst both teachers and the authorities. Cooper (1970) and Comins (1992) pointed out that teachers seem to accept that the voice will inevitably break and they consider voice loss as an "occupational hazard". Vilkman (1999) states that “apparently one of the main underlying problems is the shortage of knowledge concerning the environmental and ergonomic aspects of voice disorders as an occupational health problem”. Historically, knowledge about occupational risks and ways in which working conditions can be improved has been growing steadily. This knowledge is leading towards the realisation that better working conditions produce better results and a longer effective working life among employees, and it has, little by little, had a positive effect on the people’s understanding of the situation. Undoubtedly, the great number of teachers who suffer from voice disorders demonstrates the vital need for improved vocoergonomics in their working environment. Efforts are therefore being made to bring the voice under the scope of safety-at-work legislation and so make the protection of the voice a responsibility of employers.

6.3.4.1. Voice training

The introduction of amplification systems will not eliminate the need for teachers to have adequate information about the voice, voice training, and knowledge about how to protect the voice. The introduction of voice training and courses in voice care and voice use have long ago proved that well trained voices have greater SPL and greater F0 range in speech (Awan, 1993; Kitzing and Åkerlund, 1993), show less manifestation of vocal fatigue (Novak et al., 1991; Gelfer et al., 1991), suffer from fewer vocal symptoms and so the voice tends to be better controlled (Comins, 1992; Ohlson, 1993; Martin, 1994; Roy et al., 2001), and the employees take less sick leave (Martin, 1994).
6.3.4.2. Improved acoustical conditions

It is well known that good acoustics are crucial both for speech discrimination and voice use. It is therefore of interest that Pekkarinen (1988, p84) points out that “little or no data are yet available on such acoustic improvements of rooms which have been controlled with speech discrimination tests”. It is clear that there is a need for such research to be carried out and for the results to be widely promulgated.

It has been shown that the reverberation time is too high in many classrooms (e.g., Crandell and Smaldino, 1994). Asha (1995) stated that a level of 0.4 s is to be recommended, especially for young listeners. Pekkarinen (1998) demonstrated that speech discrimination can be improved by reducing reverberation time in classrooms, for example by increasing the signal to noise ratio by the use of sound-absorbing panels. According to Pekkarinen (1988), sound-absorbing panels have been found particularly effective when applied so as to cover the ceilings and two of the walls of square or rectangular rooms. She also pointed out, however, that there is a risk of installing too much sound-absorbing material, so that the speech sounds cannot reach the learners because of lack of reflection.

6.3.4.3. Damped auditory feedback

Background noise in the classroom contributes to more strenuous voice use. Because of the Lombard effect (Van Heusden, 1979), teachers unconsciously use a louder voice in such conditions. The results from this study indicate lower F0 and SPL if auditory feedback is damped. Nevertheless, this may be unfavourable on the communicative point of view. Interestingly, F0 decreases relatively more than SPL which should be beneficial for the students as the loudness of the teacher’s voice is probably sustained better due to less vibration of vocal fold mucosa. Moreover, decreased vocal effort on the part of the teacher may be beneficial for the student in the long term, as the teacher experiences fewer vocal problems.

6.3.4.4. Amplification

Many classrooms are large and noisy. It has been documented that the noise level in occupied classrooms is, on average, 55 – 77 dB(A) (e.g., Markides, 1986; Airey, 1998; Berg, 1993). It has also been estimated that the teacher’s speech output varies between 58-79 dB in classroom teaching (Pekkarinen and Viljanen, 1990). To reach the goal of 15-20 dB in S/N which is recommended by ASHA (1995) for young listeners and disabled students, the SPL in teachers’ voices has therefore to reach a level of 70 to 97 dB. Considering the louder end of the range, is it really possible to force any voice into such strenuous use day after day, even when the voice has been trained effectively?

Voice training is essential, but as Vilkman (2001) says: “it can be suspected that even in the field of “vocoergonomics” i.e., the ergonomics of voice use, the conclusion will be that training of individuals is important but not sufficient to control the health hazards at work with an acceptable cost/effect ratio”. Otting et al. (1992) looked at the possibilities of training teachers to increase their vocal capacity in the classroom. He found that it was
possible to train teachers to increase their capacities, but that continuous training was necessary if teachers were to retain their increased capacity. He concluded that classroom amplification is the most effective way to increase teachers’ voice levels over and above their habitual speech levels. Roy et al.’s (2001) conclusions were that the beneficial results of amplification went further than giving the subjects vocal hygiene instruction. As Vilkman (2001) states: "Use of adequate voice amplification equipment would be the quickest and cheapest way to reduce vocal load in many overloading conditions".

Verdolini and Ramig (2001) pointed out that teachers’ voice problems cost the United States a considerable amount of money each year. In school session 2001-2002 in Iceland, the cost of providing amplification equipment (Fohhn Direct Media amplifier and Shure cordless system) in one classroom was approximately equivalent to employing a supply teacher for eight days to cover for an absentee.

However, it must not be concluded that the introduction of amplification is inevitably advantageous. In some acoustic conditions, such as when there is a long reverberation time in the classroom, amplification may produce echo. In these circumstances there may be more disadvantages than advantages in the use of amplification.

According to the results of this preliminary study an effective amplification system is an important additional element in the battle for better vocal health for teachers, and assists learners to hear better what is being taught. The implications of these findings are that whether teachers work in old or newly-built classrooms each of them should have access to an amplification system, either as part of the standard classroom fittings or provided as portable equipment, free to be deployed from room to room.

7. CONCLUSIONS

In this study the hypothesis was posed that not only would the teacher's voice be protected by amplified auditory feedback, but also that the learners would be able to hear with greater clarity, and with fewer interruptions, what the teacher was saying. This study therefore set out to investigate these twin assumptions, and the conclusions have been reached. Quantum satis the teachers and the pupils agreed that use of an amplification system in the classroom is "vocoergonomic", i.e. the teacher's voice is protected and at the same time the learners can hear the teacher's voice more clearly.

The results showed that both damped and amplified auditory feedback lowered F0 and SPL (I, II, IV) and spectral slope became steeper (I, V). They also highlighted possible gender-related differences in the effects of vocal loading which warrant further study (V). Amplification may have contributed to vocal changes that indicate normal adaptation to loading. This could be seen in a larger increase in SPL and larger decrease in spectrum slope during the working-day when amplification was used. However, those changes, typical of adaptation, may also reflect hyperfunction in a negative sense; too strong
adduction and subglottal pressure leading to fatigue changes. Nevertheless more
hyperfunctional voice production could be expected in the end of a working day when
teachers are without use of amplification than when using amplification. Voices were
evaluated as less strained and better in quality when amplification was used (V). With
amplification teachers found voice production easier and vocal symptoms were reduced,
as was fatigue in the vocal mechanism and in the body (III). The students found that the
teacher’s voice could be heard more clearly, difficulties in hearing the teacher were
reduced, concentration became easier and students paid more attention to the lessons
(III). Both teachers and students agreed that amplification contributed to decreasing
classroom chatter (III). Likewise, teachers and students agreed on a few disadvantages,
mainly technical problems and lack of knowledge on how to use the equipment.

It may be concluded that the use of amplification systems should become widespread in
the future and new classrooms should automatically be provided with amplification
systems.

Further research is required to identify the kinds of amplification equipment most suited
to the acoustics of rooms of different sizes and shapes, and those which are most user-
friendly for teachers. Technological development in this area is taking place rapidly and
unit costs of the equipment are decreasing steadily; the establishment of key design
principles by research would make it possible for appropriate technology to be developed
and available at low cost for schools and individual teachers.

Research is required to find out whether the use of amplification has implications for the
nature of classroom communication and teaching styles, and for the design of educational
programmes.

From the point of view of the practising teacher, there is much to be learned about the
influence of the long-term use of amplification on vocal parameters and vocal health.
Gender differences in vocal changes also warrant further study.
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Akureyri, September 2003
Valdis Ingibjörg Jónsdóttir
APPENDIX:

1 QUESTIONNAIRE FOR TEACHERS

1. Female ___________ Male ___________

2. Age _______________________

3. PROFESSIONAL BACKGROUND

   a) Teaching responsibilities (e.g., subjects taught)

   ___________________________________________________________
   ___________________________________________________________
   ___________________________________________________________
   ___________________________________________________________

   b) Teaching experience ________________ years

VOICE USE

   a) How many class hours a week do you teach? ________________

   b) Do you work as a travel guide?
   How many hours a day? _________ How many weeks a year? _________

   c) Do you do some acting?
   How many hours a day? _________ How many weeks a year? _________

   d) Do you work as a coach?
   How many hours a day? _________ How many weeks a year? _________

   e) Other types of work requiring voice use?
   Which ___________________________________________________________________________________________
   How many hours a day? _________ How many weeks a year? _________

*Please underline appropriate activities which may affect voice:*

4. Do you take part in sports where you are required to shout?
   Often       Occasionally       Seldom       Never

5. Do you take part in aerobics where you are required to shout?
   Often       Occasionally       Seldom       Never

6. Do you go to sports competition where you are required to shout?
   Often       Occasionally       Seldom       Never
Consumer habits that may affect the mucous membranes:

7. Do you smoke?
   a. Twenty or more a day
   b. Ten - twenty a day
   c. Less than 10 a day
   d. Occasionally
   e. Have given up smoking. How long ago?
   f. Have never smoked

8. Coffee:
   How many cups of coffee do you drink each day, approximately? ______

   Please underline appropriate
   Medicine may affect the mucous membranes:

9. a) Have you used in the past year any nasal sprays which are known to dry out the mucous membranes?
   Always  Often  Occasionally  Seldom  Never

   b) Do you take steroids or other hormonal medicines?
   Always  Often  Occasionally  Seldom  Never

   c) Do you take medicines for high blood pressure?
   Always  Often  Occasionally  Seldom  Never

   Please tick as appropriate
   Medical condition that may affect your voice:

10. a) Do you suffer from allergies?
    b) Do you suffer from asthma?
    c) Do you suffer from hearing loss?
    d) Do you suffer from gastro-oesophageal reflux?

   Medical history

11. Have you been to an ear nose and throat specialist because of your voice?
   a) How often in your career? ____________
   b) Did you require medical treatment?
      Yes _______ No ______
   c) Did you require treatment from speech pathologist
      Yes _______ No ______
12. Have you had flu more than four times a year?
   Yes________  No_______

   Voice training is important for using your voice properly

13 a) Have you ever had any vocal training, e.g., singing lessons?
   If so, for how many years _____________

   b) Have you been in a choir?
   If so, for how many years? _____________

   Keys to questions 14
   Please tick as appropriate

   1. Hardly ever (i.e. less than once or twice a year)
   2. Seldom (i.e. up to four or five times a year)
   3. Sometimes (i.e. about once a month)
   4. Often (i.e. every week)
   5. Almost always (i.e. every day)

14. Do you experience?:

   Dry throat 1 2 3 4 5
   Sore throat 1 2 3 4 5
   Tickly throat 1 2 3 4 5
   Lump in the throat 1 2 3 4 5
   Hoarseness without a cold 1 2 3 4 5
   Voice failure (pitch breaks) while teaching 1 2 3 4 5
   Voice failure when not suffering from a cold 1 2 3 4 5
   Voice fails to project in noisy surroundings 1 2 3 4 5
   Voice fails to last in teaching 1 2 3 4 5
   Voice fatigue while reading 1 2 3 4 5
   Voice fatigue while singing 1 2 3 4 5
   Voice fatigue in conversation 1 2 3 4 5
15. When do you suffer from these symptoms? Please tick as appropriate

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Always</th>
<th>Often</th>
<th>Occasionally</th>
<th>Seldom</th>
<th>Never</th>
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</thead>
<tbody>
<tr>
<td>In the evenings</td>
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<tr>
<td>In the mornings</td>
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<td>During the weekends</td>
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<td>During the autumn</td>
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<td>During the winter</td>
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<td>During the spring</td>
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<tr>
<td>While teaching</td>
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<tr>
<td>During the summer</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

16. Have you taken time off from work because your voice failed?
Yes______________No_____________

17. Please tick as appropriate.
Have you been concerned that your pupils have sometimes had difficulty in hearing you?
Always       Often       Occasionally       Seldom       Never

It is known that stress can affect voice quality.

18. Please mark on a scale of 8 the degree to which you find teaching stressful:

1  2  3  4  5  6  7  8
19. How would you describe your own voice?:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
2 QUESTIONNAIRE FOR TEACHERS

Date ___________ Year ________________

Gender _______________ Class ________________

1. For how many class hours have you been using the amplifying system _________?

2. Are there advantages for the teacher in using a microphone?:
   Considerable _____ Fairly ________ Not much ________ None ________

Advantages (please tick to appropriate):

3. Is it easier to speak?
   Considerably _____ Fairly ________ Not much ________ Not ________

4. Do you think pupils pay more attention?
   Considerably _____ Fairly ________ Not much ________ No ________

5. Less chatter in classroom?
   Considerably _____ A fair amount _____ Not much ________ No ________

6. Do you have to repeat yourself if you use an amplifying system?
   Considerably _____ A fair amount _____ Not much ________ None ________

7. Do you have to repeat yourself if you don’t use an amplifying system?
   Considerably _____ A fair amount _____ Not much ________ None ________

8. Do you talk more if you are using an amplifying system?
   Considerably _____ A fair amount _____ Not much ________ None ________
9. Do you find any differences in your voice use if you use amplifying system? How?
__________________________________________________________________
__________________________________________________________________
__________________________________________________________________

10. Do you feel physically less fatigued if you are using the amplifying system? Considerably ______ A fair amount_____ Not much_______ None_______

11. Do you feel less fatigue in your vocal mechanism if you are using an amplifying system? Considerably _____ A fair amount_____ Not much_______ None_______

12. In which part of the vocal mechanism do you feel fatigue ?
A) When you are using the amplifying system
   _____ Tongue _____ Lips _______ Jaws _________ Pharynx

   B) When you do not use amplifying system
   _____ Tongue _____ Lips _______ Jaws _________ Pharynx

13. Describe in a few words possible disadvantages of using amplification
3 STUDENTS’ QUESTIONNAIRE

Date.......................... year..................

Male………. Female ………

Subject..............................

Class .........................

School..............................

Please underline the appropriate word(s):

Is it better when the teacher is using amplification?
   very much better  much better  a little better  no better

Advantages:
When the teacher is using amplification -

- Is listening easier?
   very much easier  much easier  a little easier  not easier

- Is it easier to follow the lessons?
   very much easier  much easier  a little easier  not easier

- Is there less class chatter?
   very much less       much less      a little less  no less

- Is it easier to hear the teacher through class chatter?
   very much easier  much easier  a little easier  not easier

- Are there fewer repetitions from the teacher?
   very many fewer  many fewer  just a few  no fewer

- Is it easier to concentrate on the lessons?
   very much easier  much easier  a little easier  not easier

- Do you find the lessons more interesting?
   very much  much  a little  not

Would you remind your teacher to use the amplification if she/ he forgot to turn it on? Yes_____  No _____  Don’t know_________
Write down one or two sentences about what seem to you to be the advantages of using amplification.

................................................................................................................................................
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Disadvantages

Do you find amplification
very annoying    annoying    a little annoying    not annoying

Do you find the amplification equipment uncomfortably noisy?
very noisy    noisy    a little noisy    not noisy

Write down one or two sentences about what seem to you the disadvantages of the use of amplification
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Any other comments
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TIIVISTELMÄ

Opettajilla ympäri maailman esiintyy paljon ääniongelmia. Epäsuotuisia äänenkäyttöolosuhteita (suuret luokkahuoneet, huonot akustiset olosuhteet, taustamelu) pidetään keskeisenä syyänä ongelmiiin. Ne myös vaikuttavat negatiivisesti oppilaiden kuuntelumahdollisuuksiin (huono signaali-kohina-suhdet ja taustamelu). Huonoista äänenkäyttöolosuhteista aiheutuu usein äänihuulilla kuormittava äänentuotto (kohonnut F0, SPL ja hyperfunktionaalinen äänentuotto), jossa äänihuuliten välinen törnäyspaane on suuri. Tästä voi seurata äänen väsymistä ja jopa patologisia muutoksia äänihuulilukukseen.

Tässä tutkimuksessa tarkasteltiin sähköisen äänenvoimistuksen käyttöä luokkahuoneessa eräänä mahdollisena keinona parantaa opettajien ääniergonomiaa ja oppilaiden kuuntelumahdollisuuksia. Tutkimus koostuu viidestä kansainvälisessä tieteellisessä aikakausilehdessä julkaistusta artikkelista.

Tutkimuksessa tarkasteltiin (1) kuullun äänen sähköisen voimistamisen sekä korvatulppien avulla tapahtuvan vaimentamisen vaikutuksia puheäänen parametreihin laboratorio-olosuhteissa, (2) kuullun äänen sähköisen voimistamisen vaikutuksia opettajien äänen parametreihin luokkahuonepuheessa ja (3) kerättiin kyselylomakkeiden avulla tietoa oppilaiden/opiskelijoiden ja opettajien mielipiteistä sähköisen äänenvoimistuksen käytöstä.

Laboratorio-olosuhteissa äänitettiin kuutta naispuolista (suomalaista) koehenkilöä, joilla ei tiedetty olevan äänen tai kuulon ongelmia. Luokkahuoneolosuhteissa äänitettiin viittä islantilaista opettajaa (3 naista, 2 miestä), joilla kaikilla oli eriasteisia ääniongelmia, muttei organisia muutoksia äänihuulissa. Kyselytutkimukseen osallistui 33 islantilaista opettajaa (26 naista, 7 miestä) ja 791 oppilasta/opiskelijaa (446 naispuolista, 345 miespuolista). Tutkimukseen osallistui opettajia sekä peruskoulusta, lukiosta että yliopistosta.

Koehenkilöt lukivat laboratorio-olosuhteissa saman tekstin (133 sanaa, ei /s/-äännettä) kaksi kertaa peräkkäin 1. (a) normaaliolosuhteissa ja (b) oma ääni voimistettuna kuulokkeissa ja 2. (a) normaaliolosuhteissa ja (b) korvatulpat korvissa. Testien 1 ja 2 välillä oli aikaa 2 - 6 kk. Molemmat testit toistettiin aamupäivällä ja iltapäivällä ja kolmena eri päivänä (ensimmäiset kokeet peräkkäisinä päivinä, kolmas kerta viikon kuluttua). Näytteistä analysoidiin F0 ja SPL (sekä kokonais-SPL että eri taajuuskaistojen SPL-arvot) Intelligent Speech Analyser (ISA) -puheanalyysilaitteistolla, jonka on kehittänyt DI Raimo Toivonen.

Opettajat äänittivät kannettavalla Dat-nauhurilla ja päätäntamikrofonilla luokkahuonepuhetaan viikon raskaimman työpäivän ensimmäisellä ja viimeisellä oppitunnilla kahtena päivänä viikon väläin, ensimmäisellä kerralla ilman äänenvoimistusta, seuraavalla viikolla käyttäen luokassa sähköistä äänenvoimistusta. Ennen toista äänitystä opettajat totuttelivat äänenvoimistuksen käyttöön viikon verran.
Oppituntipuheesta analysoitiin kultakin oppitunnalta 4 minuuttia (artikkelit II ja IV) tai 2 minuuttia (artikkelin V) tunnin alusta, keskeltä ja lopusta. Näytteistä mitattiin F-J Electronicsin analogisella mittarilla F0 ja SPL (Artikkelit II ja IV) ja laskettiin fonaatioaika sekä tehtiin ISA:lla keskiarvospektrianalyysi (artikkelin V).


Tulokset viittaavat siihen, että sähköisen äänenvoimistuksen käyttö piententää äänielimidöön kohdistuvaa kuormitusta opettajan työpäivän aikana. Mitattujen ääniparametrijen kasvu työpäivän aikana näyttää heijastavan normaalia adaptaatiota äänilaitteessa, sillä muutokset olivat suurempia ja koettu äänen väsyminen pienempiä käytettäessä sähköistä äänenvoimistusta.

Tulosten perusteella näyttäisi olevan syytä tarjota opettajille mahdollisuus sähköisen äänenvoimistuksen käyttöön luokkahuoneissa. Huomioita pitäisi kiinnittää sekä siihen, että laitteisto soveltuu tilaan, jossa sitä käytetään että opettajien riittävään käytönopastukseen.